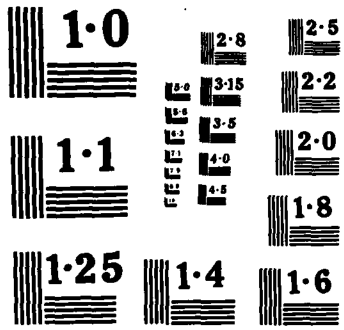
AD-A155 773 STUDY OF ACCEPTANCE CRITERIA FOR JOINT DENSITIES IN BITUMINOUS AIRPORT PA..(U) CLEMSON UNIV S C DEPT OF CIVIL ENGINEERING J L BURATI ET AL. FEB 85 1/2

UNCLASSIFIED DOT/FAA/PM-85/5 DTFA01-81-C-10057 F/G 1/5 NL



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Program Engineering
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Washington, D.C. 20591

Study of Acceptance Criteria for Joint Densities in Bituminous Airport Pavements

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February 1985

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U.S. Department of Transportation
Federal Aviation Administration

NOTICE

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT/FAA/PM-85/5	A155772	

4. Title and Subtitle	5. Report Date
STUDY OF ACCEPTANCE CRITERIA FOR JOINT DENSITIES IN BITUMINOUS AIRPORT PAVEMENTS	February 1985
	6. Performing Organization Code
7. Author(s) Burati, J.L. and Elzoghbi, G.B.	8. Performing Organization Report No.
9. Performing Organization Name and Address Department of Civil Engineering Clemson University Clemson, SC 29631	10. Work Unit No. (TRAIS)
	11. Contract or Grant No. DTFA01-81-C10057
	13. Type of Report and Period Covered FINAL REPORT
12. Sponsoring Agency Name and Address U.S. Department of Transportation Federal Aviation Administration Program Engineering and Maintenance Service Washington, DC 20591	14. Sponsoring Agency Code APM-740

15. Supplementary Notes

16. Abstract

This report summarizes a research ~~project~~ to: 1) collect data on field projects to determine joint density values currently obtained in the field on bituminous runway paving projects; 2) determine whether correlation exists between mat density and joint density results; 3) determine whether correlation exists between the results for nuclear density gages and the core densities obtained in the field; and 4) determine whether to use nuclear density gages in the acceptance plan for bituminous runway pavements.

Data were collected on 2 runway paving projects selected by the FAA Eastern Region during the spring of 1984 using 3 nuclear density gages (CPN M-2, Seaman C-75BP and Troxler 3411-B). These data were analyzed statistically to identify current production capabilities and possible correlations between mat and joint density results and between nuclear gage readings and core results.

The findings indicate that joint density values are statistically significantly lower and more variable than density values attained in the paving mat. Statistically significant differences were also found in the nuclear gage results on both projects studied. The nuclear gage results were also significantly lower than corresponding core densities. Regression analyses indicated that the level of correlation among the core and gage results varied from gage to gage and from project to project.

It is recommended that nuclear gages not be simply ~~be~~ substituted for cores in the current FAA acceptance procedures since the procedure is based on historical core data and the gage results do not necessarily correlate well with the core results.

17. Key Words	18. Distribution Statement
Bituminous Pavements, Acceptance Plans, Pavement Density, Joint Density, Nuclear Density Gages	This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	109	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

ACKNOWLEDGMENTS

This research was sponsored by the Federal Aviation Administration. The authors are indebted to personnel of the Federal Aviation Administration Eastern Region for information concerning suitable projects.

The research described in this report was carried out under the sponsorship of the Federal Aviation Administration. However, the analyses of data and all conclusions and recommendations are the responsibility of the authors and may not necessarily reflect the official views or policies of the Federal Aviation Administration. This report does not constitute a standard, specification, or regulation.

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As noted in Chapter 3, on the Morristown project the nuclear gage joint density readings were obtained with the gages oriented parallel to the joints. On the Rochester project 2 nuclear gage joint density readings were taken at each location with each gage. One with the gage parallel with the joints and one with the gage perpendicular to the joints. Table 4.15 presents the results for the readings taken with the gages perpendicular to the joints.

To investigate whether the Rochester joint nuclear gage results were closer to the core results because of the different orientation of the gages while readings were taken, an analysis of gage readings taken parallel to the joints on the Rochester project was also conducted. The results of this analysis are presented in Table 4.16. As can be seen in this table, for each of the gages the readings taken perpendicular to the joints were higher than those taken parallel to the joints. Since the core values were higher than the gage results, it would seem that the perpendicular gage orientation provides results that are closer to the core densities. The correlations between the gage and core results for perpendicular and parallel orientations are presented in the following section.

Correlation Analysis

Since all 3 gages were used to obtain density values at each coring location, it is possible to correlate the results of each of the individual gages with the core density results. Table 4.17 presents the results of this correlation analysis. For mat density, the correlation coefficients for Morristown are higher than those for Rochester. Even though the Rochester correlations are lower than those at Morristown, they are all significantly different from zero at the .002 level.

The Rochester coefficients are higher for the parallel orientation than for the perpendicular gage orientation, but they are of the same general magnitude. It is interesting to note that for Morristown the mat correlations are higher than the joint correlations, while at Rochester the reverse is true, i.e., the joint correlations are higher than the mat correlations. All of the correlations, however, are large enough to be statistically significant at the .002 level.

Regression Analysis

To further investigate the relationships between each of the gages and the core densities, regression analyses were conducted on the data. Linear regression analyses were conducted on the data from each project and for each gage individually. The analyses were performed to determine how well each gage predicted the core density results. The results of the regression analyses are presented in Tables 4.18 - 4.21. Tables 4.18 and 4.19 present the mat density results for the Morristown and Rochester projects, respectively. The joint density results appear in Tables 4.20 and 4.21.

gages produced even by a single gage manufacturer.

Scatter Plots

Plots of the density results for each gage versus the core density results are presented in Figures 4.15 - 4.17 for Morristown and Figures 4.18 - 4.20 for Rochester. The mat and joint density results are distinguished in each of the plots by the letters M and J. Figures 4.15, 4.16 and 4.17 present plots of the CPN, Troxler and Seaman results, respectively, against the corresponding core densities.

The data in Figures 4.15 - 4.17 are more scattered than the corresponding plots for each of the nuclear gage results against each other gage that are presented in Figures 4.9 - 4.11. The linear relationships between the gages in Figures 4.9 - 4.11 are not apparent in the gage versus core plots (Figures 4.15 - 4.17) due to the increased spread among the data values. It appears that there is a much higher degree of correlation between the gages than there is between the gages and the core densities. Plots similar to those in Figures 4.15 - 4.17 are presented for the Rochester project in Figures 4.18 - 4.20. The plots for the Rochester data appear to be even more scattered than those for Morristown.

Hypothesis Testing

To further investigate the relationships between the gage densities and the core results, the TTEST procedure was used to test the hypotheses that the means and variances of each of the gages were equal to the core values. F-statistics and t-statistics were determined individually for the mat and joint density results for each gage for each project. The results of the hypothesis tests are presented in Tables 4.12 - 4.15. The Morristown results appear in Tables 4.12 and 4.14. The Rochester results are in Tables 4.13 and 4.15.

The mat density results for the 2 projects are presented in Tables 4.12 and 4.13 for Morristown and Rochester, respectively. For both Morristown and Rochester, for each of the 3 gages both the means and variances are statistically significantly different than the core results at the .03 level of significance. These results, along with the visual inspection of the plots discussed above, indicate that the nuclear gages provide lower mat density values than are obtained from cores. It also appears that for mat density the nuclear gage results are slightly more variable than the core results.

The hypothesis test results for joint density are presented in Tables 4.14 and 4.15 for the Morristown and Rochester projects, respectively. For Morristown (Table 4.14), all of the gages provided statistically significantly lower mean values (.0001 level) and higher variance values (.01 level) than the core joint density results. This trend was not found in the Rochester data. For Rochester, the CPN and Seaman mean joint density values were significantly different (.022 level) than the core mean. The CPN mean was smaller than the core mean, while the Seaman mean value was larger than the core mean value. The

The hypothesis test results for joint density are presented in Tables 4.6 and 4.7. As with the mat density results, the CPN gage had the lowest mean (.0001 level of significance). The Seaman mean was larger than the Troxler mean at the .03 significance level. On the Rochester project there were no significant differences among the 3 standard deviations for the gages. For Morristown, the Seaman standard deviation was larger than the Troxler value (.04 level of significance), but was not significantly larger than the CPN value at the .11 significance level.

It is not possible to establish trends with only 2 projects. However, it can be concluded from Tables 4.4 - 4.7 that the 3 gages will not always produce the same mean results, and that the variability may differ from gage to gage.

Correlation Analysis

Since all 3 gages were used to obtain density values at each location, it is possible to correlate the individual values on a pairwise basis between the gages. Tables 4.8 - 4.11 present the results of the correlation analysis. Tables 4.8 and 4.10 present the correlation coefficients for mat and joint density, respectively, for each gage combination for the Morristown project. Tables 4.9 and 4.11 present similar results for Rochester.

The correlation coefficients among the 3 gage combinations are very similar for each project when considered individually. However, the coefficients for Morristown are consistently larger than the ones at Rochester. For Morristown, the mat density coefficients are 0.81, 0.82 and 0.85 for the CPN/Troxler, CPN/Seaman and Troxler/Seaman comparisons, respectively. For Rochester, the coefficients are 0.58, 0.59 and 0.60 for the same comparisons. Similar results are exhibited for the joint density correlations in Tables 4.10 and 4.11. The joint density correlations for Rochester are not as uniform as the joint density results for Morristown (Table 4.9). They are, however, still consistently lower than the Morristown joint density results. It appears that the gages correlate equally well with one another, but that the level of correlation may vary from one project to the next.

Gage versus Core Comparisons

If nuclear density gages are to be considered for use in acceptance decisions, it is desirable to investigate how well their results compare with the method that is currently used for this purpose, i.e., the use of core densities. The core and nuclear density results on each of the projects were analyzed to determine how well the gage results correlated with the core densities.

It should be noted that any conclusions and discussions presented in this report can apply only to the gages used in the study. They can not necessarily be applied to a particular manufacturer's gages in general since there is bound to be some degree of variability among the

Scatter Plots

Plots of the density values obtained by each of the 3 gages are presented in Figures 4.9 - 4.11 and 4.12 - 4.14 for the Morristown and Rochester projects, respectively. The mat and joint density results are distinguished in each of the plots by the letters M and J. As expected from the discussions above, the mat density values are generally higher than the joint results for all of the plots. Figures 4.9, 4.10 and 4.11 present plots of CPN versus Troxler, CPN versus Seaman and Troxler versus Seaman density results, respectively, for the Morristown project.

As shown in the plots in Figures 4.9 - 4.11, there is generally a linear relationship between each of the pairwise combinations of gages. The values fall close to a straight line with relatively little dispersion about the line. There appears to be more scatter in the joint density results than in the mat density values. This reflects the higher variability in the joint density values that is identified in Table 4.2.

Plots similar to those in Figures 4.9 - 4.11 are presented in Figures 4.12 - 4.14 for the Rochester project. There is more scatter in the data for Rochester than is found in the plots for Morristown. The data are more spread out and the linear relationship of Figures 4.9 - 4.11 is less pronounced. There appears to be much less correlation between the gage results in Figures 4.12 - 4.14 than is present in Figures 4.9 - 4.11. The reason for this difference is not known, but may in some way be related to the fact that joint density was not used as an acceptance variable on the Rochester project or to differences in the paving mixes and materials for the 2 projects.

Hypothesis Testing

To further investigate the data plotted in Figures 4.9 - 4.14, the TTEST procedure was used on a pairwise basis to test the assumptions of equal means and variances between the results of the gages. The possible pairwise comparisons include: 1) CPN with Troxler, 2) CPN with Seaman and 3) Troxler with Seaman. These comparisons were made individually for each of the projects, and for both the joint and mat density results. The results of the hypothesis tests are presented in Tables 4.4 - 4.7. The Morristown results are in Tables 4.4 and 4.6, while the Rochester results appear in Tables 4.5 and 4.7.

Visual inspection of the statistics in Tables 4.4 and 4.5 identifies a trend in the relative magnitudes of the mat density means of the 3 gages. On both projects, the Seaman gage produced the largest mean value, followed by the Troxler and then the CPN gages. If the t-statistics are considered, the Seaman mean at Morristown is not significantly different from the Troxler mean at the .11 level of significance. There is little consistency in the standard deviation values for the mat density results. The Seaman gage had the largest (.10 level of significance) standard deviation for Morristown, but had the smallest (.16 level of significance) standard deviation for Rochester.

results, the Morristown mat and joint variances are not significantly different (.269 level of significance), but the Rochester values are significantly different at the .0001 level.

The t-statistic is used to test the hypothesis that the means of 2 data sets are equal. The term 'Prob > |t|' is the probability of obtaining a t value with absolute magnitude as large as the one shown in the table if the hypothesis, i.e., the means are equal, is true. In Table 4.1 there is essentially no chance (.0001 or less) that the means of the 2 data sets are equal for any of the 4 sources. Since similar results are displayed in Table 4.2 for Rochester, it is very reasonable to assume that the joint densities obtained are statistically significantly different from the mat densities obtained on the projects.

Correlation Analysis

Since there is no direct correspondence between the individual mat and joint density values, it is not possible to correlate the individual values. It is possible, however, to correlate the average mat and joint density values for each lot. Unfortunately, this does not provide a great deal of information due to the small number of lots (10 and 18) on each project. Table 4.3 presents a summary of the correlation coefficients between the average lot mat and joint densities for each project.

As can be seen in the table, there is a positive correlation between the average mat and joint densities on the Morristown project. While the correlation coefficients for the Rochester data are positive, the magnitudes are not large enough for 3 of the sources to preclude the possibility of zero correlation at the .05 level of significance. The core, Troxler and Seaman results are not significantly different from zero at the .087, .168, and .150 levels of significance, respectively.

Nuclear Gage Comparisons

One of the objectives of the study was to investigate how well the 3 different types of nuclear density gages correlated with each other. This was desired to determine how each gage performed in comparison with the other gages. An analysis of the performance of each of the gages with respect to the core density values is presented in a later section. This section presents the results of the correlation analysis of the 3 gages with respect to one another.

It should be noted that any conclusions and discussions presented in this report can apply only to the gages used in the study. They can not necessarily be applied to a particular manufacturer's gages in general since there is bound to be some degree of variability among the gages produced even by a single manufacturer.

Scatter Plots

Plots of the mat density and joint density values obtained on the projects are presented in Figures 4.1 - 4.8. Figures 4.1 - 4.4 present the results from the Morristown project, while the Rochester results are presented in Figures 4.5 - 4.8. Each plot presents the mean mat and joint densities for each lot along with the corresponding maximum and minimum values obtained. Figures 4.1 and 4.5 present the core density acceptance test results. Figures 4.2 and 4.6, 4.3 and 4.7, and 4.4 and 4.8, present the combined values for both the acceptance and random tests for the CPN, Troxler and Seaman gages, respectively.

As can be seen in the figures, the mat density mean values are consistently higher than the joint mean densities on both projects for the cores and for all 3 nuclear gages. It is also apparent that the joint density results are more variable than the mat density values. This is indicated by the larger spreads between the maximum and minimum values for the joint densities. These differences in means and variability are quantified in the statistics presented in the next section.

Hypothesis Testing

Data were collected from 10 lots on the Morristown project and 18 lots at Rochester. This yielded a total of 80 core densities (40 mat and 40 joint) and 384 readings for each of the 3 nuclear gages (total of 1152 nuclear density values) at Morristown. At Rochester, a total of 144 core densities (72 mat and 72 joint) and 1242 nuclear gage readings (414 for each of the gages) were obtained. The data from these readings are summarized on a lot-by-lot basis in Appendix A.

To further investigate the trends with regard to the mean densities and the variability identified in the plots in Figures 4.1 - 4.8, the TTEST procedure (PROC TTEST) in SAS was used to perform hypothesis tests on the data. PROC TTEST conducts hypothesis tests to test the assumptions of equal variances and equal means between 2 sets of data. In this case, the 2 sets of data to be tested are the mat and joint density results from the 2 projects. Tables 4.1 and 4.2 present the hypothesis test results for the data from Morristown and Rochester, respectively.

In Table 4.1, the source column identifies whether the mean is from the core, CPN, Troxler or Seaman density values. The last 2 columns list the results of the F-tests and t-tests conducted on the data. The F-statistic is used to test the hypothesis that the variances of the 2 data sets are equal. The term 'Prob > F' is the probability of obtaining an F value as large as the one shown if the hypothesis, i.e., the variances are equal, is true. In Table 4.1, therefore, there is 0.0001, or less, chance that the variances of the mat and joint densities are equal for any of the 3 nuclear gage results. Similar results are exhibited in Table 4.2 for the Rochester data. These are sufficient grounds to assume that the joint density values are more variable than the mat densities when using nuclear gages. For the core

CHAPTER IV

RESULTS OF DENSITY DATA ANALYSIS

The results of the data analysis procedures outlined in the previous chapter are presented and discussed in this chapter. All plots and statistical analyses were conducted using the Statistical Analysis System (SAS) (4). The relationship between mat density and joint density is considered first. The relationships among the nuclear gage results are presented next. Finally, the correlations between the nuclear gage results and the core density values are discussed.

In Chapter 2 it was indicated that density readings were obtained where cores were drilled for acceptance purposes and at other random locations within each lot. In the discussions which follow, density readings (core or nuclear) taken at coring locations are referred to as acceptance tests. Nuclear gage readings taken at locations where cores were not drilled are referred to as random tests.

Mat Density versus Joint Density

Among the research objectives stated in Chapter 1 were the determination of the joint density values currently obtained in the field and the determination of whether correlations exist between mat and joint density results. The data collected on the 2 field projects were analyzed to achieve these objectives.

Project Specification Requirements

The specification requirements for joint density differed on the 2 projects studied. On the Morristown project, joint density was an acceptance item with a payment adjustment provision included in the contract. There was a definite incentive for the contractor to achieve dense joints since there was the potential for payment reductions if the specification requirements were not met. The specifications at Morristown stipulated that 4 cores be drilled at random locations along the joints for each lot. An estimated PWL value of 90 or greater was required for 100 percent payment. The lower acceptance limit was 94.3 percent of the laboratory Marshall density.

There was no specification requirement for joint density on the Rochester project. Four cores were drilled and tested by the researchers at random locations along the joints for each lot. However, the incentive to achieve high joint densities associated with the price adjustment provisions on the Morristown project was not present at Rochester. This difference in payment provisions between the 2 projects may have an effect on the joint densities obtained at the respective sites.

Correlation Analysis

In addition to the scatter plots, correlation coefficients were calculated to quantify the relationships among the data. A correlation coefficient measures the amount of association between 2 variables, and is based on a linear relationship. The correlation coefficient is defined by:

$$r = \frac{\sum_{i=1}^{N} (Xi - \bar{x})(Yi - \bar{y})}{\sqrt{[\sum_{i=1}^{N} (Xi - \bar{x})^2]\,[\sum_{i=1}^{N} (Yi - \bar{y})^2]}}$$

where:

r = sample correlation coefficient
N = number of samples
Xi = sample values for one variable
Yi = sample values for the other variable

$\bar{x}$ = mean of the Xi variables

$\bar{y}$ = mean of the Yi variables.

The sample correlation coefficients can range from -1.0 to +1.0. Negative correlation coefficients imply that as one variable increases the other decreases, whereas positive correlations imply that as one variable increases the other also increases. The magnitude of the correlation coefficient represents the significance of the relationship between the 2 variables. Coefficients near zero result from scattered data, and indicate that as one variable increases there is no consistent effect on the other variable.

In the correlation analysis, coefficients were calculated for the relationships 1) between mat and joint density, 2) between each nuclear gage and each of the other nuclear gages, 3) between core densities and the results for each of the nuclear gages, and 4) between the mat and joint percent compaction values for the cores and for each gage.

Regression Procedure

Regression analyses were conducted on the data to further investigate the relationships between each of the nuclear gage densities and the core densities. Linear regression analyses were conducted on the data from each project individually. Regression analyses were conducted on the results from each nuclear density gage to determine how well each gage predicted the core density results. Similar regression analyses were conducted on the percent compaction values for each project.

CHAPTER III

DATA ANALYSIS

After collection, the data were transferred to the computer in preparation for analysis. Separate analyses were conducted for each project. The Statistical Analysis System (SAS) (4) was used for both the data management and the analysis. Scatter plots of the data were developed to visually investigate trends in the data. A number of statistical tests were conducted to quantify the trends in the data and the relationships among the data. The statistical procedures used include determination of correlation coefficients, hypothesis testing, and regression analysis.

Scatter Plot Procedure

Scatter plots of the data were developed to investigate trends and correlations 1) between the results of each nuclear gage and the core densities, 2) among the readings from the 3 nuclear gages, and 3) between the average mat and joint density for each lot. The data were also plotted by lot number to determine whether any time trends were present. Since density values for acceptance decisions on the projects studied were based on percent compaction, i.e., the percentage of the laboratory Marshall density value that was attained by the field cores, the core and gage density results were also converted to percent compaction values and then plotted.

To identify the trends between nuclear gage readings and core densities, for each project the readings for each gage were plotted against their corresponding core density. To investigate correlations among the gages, the readings for each gage for each location were also plotted against the readings from each of the other gages. To determine the relationship between mat and joint density, for each project the average mat density and the average joint density for each lot were plotted against the lot number. The percent compaction values for each gage were also plotted against the core percent compaction results.

Hypothesis Tests

To determine whether mat densities differed from joint densities on each project, t-tests and F-tests were used to compare the mat and joint density means and variances for each lot of material. The TTEST procedure in SAS computes a t-statistic for testing the hypothesis that the means of 2 groups of observations, e.g., mat and joint densities, are equal and an F-statistic for testing the equality of the variances. In addition to comparing mat and joint density means and variances, t-tests and F-tests were used to compare the means and variances of the readings for each nuclear density gage. This was done to determine whether the gages provided different results. The TTEST procedure was also conducted on the mat and joint percent compaction results for each project.

the surface. The air-gap ratio method is used by Seaman to reduce the effect of the chemical composition of the mixture on the gage density readings.

Data for each project consisted of the densities of the compacted pavement materials. The compacted materials were tested on a lot basis, with a lot consisting of one day's production, not to exceed 2000 tons. Eight cores were selected for each lot, 4 for the mat and 4 for the joints. The contractor was responsible for drilling the cores, while the resident engineer was responsible for sending the cores to the laboratory for acceptance testing. At Rochester, since there was no acceptance requirement for joint density, the joint cores that were drilled were returned to Clemson University for determination of the core densities by the research staff.

The core locations on the mat and the joint were identified by the resident engineer on the project. The random sampling and testing procedures used on the projects are outlined in the Eastern Region Laboratory Procedures Manual (ERLPM) (5).

After allowing a 10-minute warm-up period, a standard count was taken each working day for each gage. For the Seaman gage, an air-gap reading was taken for each lot. Care was taken to ensure that gages were firmly seated at each location where readings were taken. The pavement surface was very dense and smooth; therefore, no filler material was needed to prevent air gaps. Care was taken to ensure that all manufacturers' operating procedures were followed for all readings taken.

Readings were obtained with each of the 3 nuclear density gages at the exact locations where cores were to be drilled. The nuclear readings were taken immediately before drilling to guarantee no change in pavement density between the time of the nuclear gage readings and the drilling of the cores. While one gage was being used, the other 2 gages were at least 30-feet away to ensure that they would not affect the reading being taken. While taking the joint density readings, at Morristown the gages were oriented so that the radiation source and the detector were aligned longitudinally with the joint. On the Rochester project, 2 joint readings were obtained for each sample location. One with the gage parallel to the joint (as at Morristown) and one with the gage perpendicular to the joint.

After drilling, each core was numbered and the same identification number was placed on a marker. Both the core and the marker were placed in a plastic bag for shipment to the laboratory. Before being sent to the laboratory for testing, each core identification number was checked by the research staff to ensure that the correct identification number was placed on each core.

CHAPTER II

DATA COLLECTION

The portion of the research dealing with data collection was divided into 2 main areas. The first was to determine the type of data to collect. The second was to ensure consistency in the data collection procedures to limit variability. Data for the research were gathered on 2 construction projects during 1984. The projects were selected by the FAA Eastern Region. Data were to have originally been collected on 3 projects, but the Eastern Region was only able to identify 2 suitable projects for which joint data could be obtained.

Type of Data

For research purposes on the projects studied, 4 cores were collected for determining joint density in addition to the 4 cores normally drilled for mat density determination. Nuclear gage readings were also taken at locations where cores were drilled to identify whether correlations between the nuclear gages and the core density results exist. These correlations can be used to determine whether nuclear gages can be used as an alternative to cores for acceptance decisions. To ensure consistency in the collection of data, all nuclear density readings were taken by the research staff. These data were collected in accordance with the contract specifications and in the manner discussed in the pre-construction meetings attended by the research staff. Nuclear gage readings were also taken at random locations on the joints and within the mat. The ease and speed of the nuclear gages allowed a large number of locations (approximately 30) to be selected from each paving lot.

Data Collection Procedures

Two projects were selected by the FAA Eastern Region for the collection of field data. The projects studied were the Morristown, NJ Municipal Airport and the Rochester-Monroe County Airport in Rochester, NY. Data were collected on the projects by the research staff using 3 different gages (Troxler 3411-B, Seaman C-75BP, CPN M-2). The Troxler and CPN gages have Cesium-137 sourses, while the Seaman gage has a Radium-226:Beryllium source. While the Troxler and CPN gages both operate in the backscatter mode, the CPN gage has 2 backscatter modes, BS or AC. The AC mode is used on thin-lift asphaltic concrete and the BS mode is used on deeper lifts. The BS mode was used in the research because it provided density values closer to the core results.

The Seaman gage operates differently than the other 2 gages. It uses the 'air-gap ratio' method. The air-gap ratio mode consists of taking 2 readings, one recording the radiation backscatter with the gage in direct contact with the surface, and the other recording the radiation backscatter with an air-gap of approximately 1.5-inches above

Research Benefits

The use of nuclear density gages for acceptance purposes has potential advantages over the use of cores. Nuclear density gages provide a rapid, non-destructive method for pavement evaluation. More samples can be obtained per lot with nuclear gages than with cores because the gage readings can be made in a matter of minutes and do not require the drilling and patching of holes in the pavement.

Since runways are relatively wide, up to 150 feet or more, there are many longitudinal construction joints required. Since limited data indicate joint densities to be lower than mat densities, it is possible that these lower densities may lead to more rapid pavement deterioration at the joints. The research will help to establish joint densities currently obtained on projects and whether these densities are lower than those obtained on the mat. This will help to determine whether joint density should be considered separate from mat density in acceptance decisions.

2. determine whether correlation exists between mat density and joint density results,

3. determine whether correlation exists between the results of nuclear density gages and the core densities obtained in the field, and

4. determine whether to use nuclear density gages in the acceptance plan based on the correlations identified in objective 3.

Research Procedure

To meet the outlined objectives, the research was conducted in 3 major phases. First, field data were gathered on construction projects using 3 nuclear density gages (Troxler 3411-B, Seaman C-75BP, and CPN M-2). Next, these data were analyzed statistically to identify current production capabilities and possible correlations between mat and joint density results and between nuclear gage readings and core densities. Finally, the results of the first 2 phases were used to investigate potential tolerance limits and acceptance procedures.

Data Collection

To assure consistency in the data collection phase, all joint and mat density data were collected using the same 3 nuclear density gages. Nuclear density readings were taken where mat and joint cores were drilled for acceptance testing. Additional nuclear density readings were taken with each gage at random locations to evaluate correlations among the nuclear gage results and between the mat and joint densities.

Data were collected on 2 bituminous pavement construction projects in 1984. The research staff that collected the data attended classes offered by the gage manufacturers to ensure proper training in the operation of the gages prior to the collection of data. Pre-construction meetings were held at each project site to make all parties involed aware of the research effort and of the cooperation needed from the testing laboratories during the data collection.

Data Analysis

A statistical analysis was conducted on the data to determine parameters that can be used to represent the field construction process capability. Mean and standard deviation values for both joint and mat densities were developed for each project. In addition, a correlation analysis was conducted to investigate the potential relationships between each of the following: 1) mat density and joint density, 2) the 3 nuclear gages, and 3) core densities and nuclear gage readings. All statistical analyses were conducted using the Statistical Analysis System (SAS) (4).

CHAPTER I

INTRODUCTION

During 1978, the Federal Aviation Administration (FAA) Eastern Region incorporated a statistically-based acceptance plan into its bituminous surface course specification (P-401). This specification provided for the determination of a price adjustment factor based on the relative acceptability of the pavement materials. In conjunction with the implementation of this specification, the FAA sponsored a research project: 1) evaluating the performance of the specification, 2) making recommendations for improving existing specifications, and 3) expanding the scope of the statistical specification to include additional acceptance characteristics (1). Subsequent research addressed the use of the Marshall properties in a price adjustment acceptance approach (2).

The introduction of joint density as an acceptance test and the use of nuclear density gages for pavement evaluation were not addressed by thorough research. Limited data suggested that joint densities are consistently lower than the mat densities (3). In 1981 the FAA instituted a price adjustment provision for joint density on its runway paving project at the National Aviation Facilities Experiment Center (NAFEC) outside Atlantic City, NJ. The FAA discontinued the use of nuclear gages for acceptance decisions after research at NAFEC showed a lack of accuracy, leading to a lack of confidence in the consistency and accuracy of nuclear gages.

The limited data from the NAFEC project are not sufficient grounds on which to base a rational acceptance plan for joint density that incorporates appropriate acceptance limits with the possible use of price adjustments. A thorough study of joint densities and nuclear gage readings obtained under field conditions is essential if the FAA is to consider using joint density and nuclear gages in its acceptance approach for bituminous pavements. To this end, 2 construction sites were selected on which to gather joint density and nuclear gage data. The findings of the research effort on these projects are presented in this report.

Research Objectives

The objectives of the research are to determine whether joint density should be included in the FAA's acceptance procedure for bituminous runway pavements and whether nuclear density gages should be introduced in the acceptance procedure. The specific objectives of the research are:

1. collect data on field projects to determine joint density values currently obtained in the field,

The tables present the regression equations using each of the gage results as the independent variable and the core density results as the dependent variable. The slopes and intercepts for the regression lines are presented along with the t-statistic for testing the hypothesis that the values (slope and intercept) are equal to zero. The R-square values presented in the tables are measures of how well the variation of the dependent variable is described by the variation in the independent variable. As can be seen in Table 4.19, the R-square values for mat density for Rochester are much smaller than the values in the other tables (4.18, 4.20, and 4.21). The low R-square values in Table 4.19 are the result of the greater variability for the mat density data at Rochester. To illustrate the spread in the data and the relationships of the regression equations to the data, Figures 4.21 - 4.26 present plots of the regression equations for each gage for each project with the mat and joint density values also shown. Figures 4.21 - 4.23 present the Morristown results, and Figures 4.24 - 4.26 present the results from Rochester.

There is no consistency between the 2 projects with respect to the plots. For Morristown, the mat density regression lines have steeper slopes than the corresponding joint density lines. The opposite is true for Rochester where the mat density regression lines have very shallow slopes. These shallow slopes are indicative of little relationship between the gage densities and the core densities. The fact that there was no price adjustment provision at Rochester, as there was at Morristown, does not appear to have been a factor in the results for the 2 projects since the Rochester project has larger R-square values for the joint density regressions than were found for the Morristown data.

TABLE 4.1. RESULTS OF HYPOTHESIS TESTS ON MAT AND JOINT DENSITY DATA FOR THE MORRISTOWN PROJECT

SOURCE	NO.	MAT MEAN (STD DEV)	JOINT MEAN (STD DEV)	F-STATISTIC (PROB > F)*	t-STATISTIC (PROB > |t|)#
CORE	40	151.5 (3.3)	145.6 (3.9)	1.43 (.269)	-7.39 (.0001)
CPN	192	147.1 (4.0)	136.5 (5.9)	2.18 (.0001)	-20.77 (.0001)
TROXLER	191	148.8 (3.9)	138.7 (5.7)	2.08 (.0001)	-19.48 (.0001)
SEAMAN	192	149.5 (4.6)	138.2 (6.6)	2.09 (.0001)	-20.19 (.0001)

* - probability of obtaining an F value as large as the one shown if the variances are actually equal

\# - probability of obtaining a t value as large as the one shown if the means are actually equal

TABLE 4.2. RESULTS OF HYPOTHESIS TESTS ON MAT AND JOINT DENSITY DATA FOR THE ROCHESTER PROJECT

SOURCE	NO.	MAT MEAN (STD DEV)	JOINT MEAN (STD DEV)	F-STATISTIC (PROB > F)*	t-STATISTIC (PROB > |t|)#
CORE	72	150.7 (2.1)	143.3 (4.3)	4.13 (.0001)	-13.07 (.0001)
CPN	207	146.3 (3.7)	141.8 (4.4)	1.40 (.016)	-11.35 (.0001)
TROXLER	207	147.7 (3.2)	143.7 (4.1)	1.64 (.0004)	-11.05 (.0001)
SEAMAN	207	150.0 (2.9)	144.6 (4.1)	1.99 (.0001)	-15.26 (.0001)

* - probability of obtaining an F value as large as the one shown if the variances are actually equal

\# - probability of obtaining a t value as large as the one shown if the means are actually equal

TABLE 4.3. CORRELATION COEFFICIENTS BETWEEN AVERAGE LOT MAT AND JOINT DENSITIES

PROJECT	SOURCE	COEFFICIENT (R)	PROB > |R|*
MORRISTOWN	CORE	.666	.036
(10 lots)	CPN	.829	.003
	TROXLER	.808	.005
	SEAMAN	.776	.008
ROCHESTER	CORE	.414	.087
(18 lots)	CPN	.496	.036
	TROXLER	.339	.168
	SEAMAN	.354	.150

* PROB > |R| - probalility of obtaining an R value as large as the one shown if the true correlation is zero

TABLE 4.4. RESULTS OF PAIRWISE HYPOTHESIS TESTS ON NUCLEAR GAGE MAT DENSITY RESULTS FOR THE MORRISTOWN PROJECT

GAGE	NO.	MEAN	STD DEV	F-STATISTIC (PROB > F)*	t-STATISTIC (PROB > |t|)#
CPN	192	147.1	4.1		
				1.06 (.711)	-3.96 (.0001)
TROXLER	191	148.7	4.0		
				1.34 (.042)	1.58 (.115)
SEAMAN	192	149.4	4.6		
				1.27 (.095)	-5.24 (.0001)
CPN	192	147.1	4.1		

* - probability of obtaining an F value as large as the one shown if the variances are actually equal

\# - probability of obtaining a t value as large as the one shown if the means are actually equal

TABLE 4.5. RESULTS OF PAIRWISE HYPOTHESIS TESTS ON NUCLEAR GAGE MAT DENSITY RESULTS FOR THE ROCHESTER PROJECT

GAGE	NO.	MEAN	STD DEV	F-STATISTIC (PROB > F)*	t-STATISTIC (PROB > |t|)#
CPN	207	146.3	3.7		
				1.31 (.053)	-4.23 (.0001)
TROXLER	207	147.7	3.2		
				1.21 (.169)	7.38 (.0001)
SEAMAN	207	150.0	2.9		
				1.59 (.001)	-11.22 (.0001)
CPN	207	146.3	3.7		

* - probability of obtaining an F value as large as the one shown if the variances are actually equal

\# - probability of obtaining a t value as large as the one shown if the means are actually equal

TABLE 4.6. RESULTS OF PAIRWISE HYPOTHESIS TESTS ON NUCLEAR GAGE JOINT DENSITY RESULTS FOR THE MORRISTOWN PROJECT

GAGE	NO.	MEAN	STD DEV	F-STATISTIC (PROB > F)*	t-STATISTIC (PROB > |t|)#
CPN	192	136.5	5.9		
				1.07 (.621)	-3.72 (.0002)
TROXLER	192	138.7	5.7		
				1.35 (.040)	-0.78 (.437)
SEAMAN	192	138.2	6.6		
				1.25 (.118)	-2.68 (.008)
CPN	192	136.5	5.9		

* - probability of obtaining an F value as large as the one shown if the variances are actually equal

\# - probability of obtaining a t value as large as the one shown if the means are actually equal

TABLE 4.7. RESULTS OF PAIRWISE HYPOTHESIS TESTS ON NUCLEAR GAGE JOINT DENSITY RESULTS FOR THE ROCHESTER PROJECT

GAGE	NO.	MEAN	STD DEV	F-STATISTIC (PROB > F)*	t-STATISTIC (PROB > |t|)#
CPN	207	141.8	4.4		
				1.12 (.418)	-4.61 (.0001)
TROXLER	207	143.7	4.1		
				1.00 (.994)	2.17 (.031)
SEAMAN	207	144.6	4.1		
				1.12 (.422)	-6.71 (.0001)
CPN	207	141.8	4.4		

* - probability of obtaining an F value as large as the one shown if the variances are actually equal

\# - probability of obtaining a t value as large as the one shown if the means are actually equal

TABLE 4.8. CORRELATION COEFFICIENTS BETWEEN NUCLEAR GAGES FOR MAT DENSITY ON THE MORRISTOWN PROJECT (191 OBSERVATIONS)

	CPN	TROXLER	SEAMAN
CPN	---	.81	.82
TROXLER	.81	---	.85
SEAMAN	.82	.85	---

NOTE - the probability that any individual coefficient in the table would be obtained if the true correlation is zero is .0001

TABLE 4.9. CORRELATION COEFFICIENTS BETWEEN NUCLEAR GAGES FOR MAT DENSITY ON THE ROCHESTER PROJECT (207 OBSERVATIONS)

	CPN	TROXLER	SEAMAN
CPN	---	.58	.59
TROXLER	.58	---	.60
SEAMAN	.59	.60	---

NOTE - the probability that any individual coefficient in the table would be obtained if the true correlation is zero is .0001

TABLE 4.10. CORRELATION COEFFICIENTS BETWEEN NUCLEAR GAGES FOR JOINT DENSITY ON THE MORRISTOWN PROJECT (192 OBSERVATIONS)

	CPN	TROXLER	SEAMAN
CPN	---	.90	.87
TROXLER	.90	---	.89
SEAMAN	.87	.89	---

NOTE - the probability that any individual coefficient in the table would be obtained if the true correlation is zero is .0001

TABLE 4.11. CORRELATION COEFFICIENTS BETWEEN NUCLEAR GAGES FOR JOINT DENSITY ON THE ROCHESTER PROJECT (207 OBSERVATIONS)

	CPN	TROXLER	SEAMAN
CPN	---	.65	.39
TROXLER	.65	---	.52
SEAMAN	.39	.52	---

NOTE - the probability that any individual coefficient in the table would be obtained if the true correlation is zero is .0001

TABLE 4.12. RESULTS OF HYPOTHESIS TESTS FOR PAIRWISE COMPARISONS BETWEEN CORE AND NUCLEAR GAGE MAT DENSITY RESULTS FOR THE MORRISTOWN PROJECT

SOURCE	NO.	MEAN	STD DEV	F-STATISTIC (PROB > F)*	t-STATISTIC (PROB > |t|)#
CORE	40	151.7	3.0	---	---
CPN	192	147.1	4.1	1.81 (.030)	8.13 (.0001)
TROXLER	191	148.7	4.0	1.72 (.047)	5.27 (.0001)
SEAMAN	192	149.4	4.6	2.31 (.003)	3.86 (.0002)

* - probability of obtaining an F value as large as the one shown if the variances are actually equal

- probability of obtaining a t value as large as the one shown if the means are actually equal

TABLE 4.13. RESULTS OF HYPOTHESIS TESTS FOR PAIRWISE COMPARISONS BETWEEN CORE AND NUCLEAR GAGE MAT DENSITY RESULTS FOR THE ROCHESTER PROJECT

SOURCE	NO.	MEAN	STD DEV	F-STATISTIC (PROB > F)*	t-STATISTIC (PROB > |t|)#
CORE	72	150.7	2.1	---	---
CPN	207	146.3	3.7	3.03 (.0001)	12.23 (.0001)
TROXLER	207	147.7	3.2	2.31 (.0001)	8.76 (.0001)
SEAMAN	207	150.0	2.9	1.91 (.002)	2.19 (.030)

* - probability of obtaining an F value as large as the one shown if the variances are actually equal

- probability of obtaining a t value as large as the one shown if the means are actually equal

TABLE 4.14. RESULTS OF HYPOTHESIS TESTS FOR PAIRWISE COMPARISONS BETWEEN CORE AND NUCLEAR GAGE JOINT DENSITY RESULTS FOR THE MORRISTOWN PROJECT (PARALLEL)

SOURCE	NO.	MEAN	STD DEV	F-STATISTIC (PROB > F)*	t-STATISTIC (PROB > |t|)#
CORE	40	145.6	3.9	---	---
CPN	192	136.5	5.9	2.29 (.003)	12.16 (.0001)
TROXLER	192	138.7	5.7	2.13 (.006)	9.33 (.0001)
SEAMAN	192	138.2	6.6	2.87 (.0002)	9.49 (.0001)

* - probability of obtaining an F value as large as the one shown if the variances are actually equal

\# - probability of obtaining a t value as large as the one shown if the means are actually equal

TABLE 4.15. RESULTS OF HYPOTHESIS TESTS FOR PAIRWISE COMPARISONS BETWEEN CORE AND NUCLEAR GAGE JOINT DENSITY RESULTS FOR THE ROCHESTER PROJECT (PERPENDICULAR)

SOURCE	NO.	MEAN	STD DEV	F-STATISTIC (PROB > F)*	t-STATISTIC (PROB > |t|)#
CORE	72	143.3	4.3	---	---
CPN	207	141.8	4.4	1.03 (.411)	2.51 (.013)
TROXLER	207	143.7	4.1	1.09 (.638)	-0.76 (.448)
SEAMAN	207	144.6	4.1	1.09 (.642)	-2.30 (.022)

* - probability of obtaining an F value as large as the one shown if the variances are actually equal

\# - probability of obtaining a t value as large as the one shown if the means are actually equal

TABLE 4.16. RESULTS OF HYPOTHESIS TESTS ON PERPENDICULAR AND PARALLEL GAGE ORIENTATIONS FOR JOINT DENSITY READINGS FOR ROCHESTER (72 OBSERVATIONS)

GAGE	PERPENDICULAR MEAN (STD DEV)	PARALLEL MEAN (STD DEV)	F-STATISTIC (PROB > F)*	t-STATISTIC (PROB > |t|)#
CPN	140.7 (4.6)	138.0 (5.0)	1.18 (.489)	-3.31 (.001)
TROXLER	142.9 (4.5)	139.8 (5.0)	1.24 (.367)	-3.91 (.0001)
SEAMAN	144.7 (4.6)	142.5 (5.4)	1.38 (.174)	-2.65 (.009)

* - probability of obtaining an F value as large as the one shown if the variances are actually equal

\# - probability of obtaining a t value as large as the one shown if the means are actually equal

TABLE 4.17 CORRELATION COEFFICIENTS BETWEEN CORE AND NUCLEAR GAGE DENSITY RESULTS

DENSITY	PROJECT	CPN	TROXLER	SEAMAN
MAT	MORRISTOWN	.71 [40]*	.81 [40]	.78 [40]
	ROCHESTER	.38 [72]	.31 [72]	.36 [72]
JOINT	MORRISTOWN (Parallel)	.63 [40]	.67 [40]	.73 [40]
	ROCHESTER (Perpendicular)	.75 [72]	.77 [72]	.63 [72]
	ROCHESTER (Parallel)	.79 [72]	.81 [72]	.80 [72]

* - [Number of observations]

NOTE - the probability that any individual coefficient in the table would be obtained if the true correlation is zero is less than .002

TABLE 4.18. RESULTS OF REGRESSION ANALYSIS ON GAGE AND CORE MAT DENSITY RESULTS FOR THE MORRISTOWN PROJECT (40 OBSERVATIONS).

GAGE	SLOPE	t-STATISTIC (PROB > $\|t\|$)*	INTERCEPT	t-STATISTIC (PROB > $\|t\|$)*	R-SQUARE
CPN	0.505	6.2 (.0001)	76.96	6.4 (.0001)	0.493
TROXLER	0.660	8.7 (.0001)	53.20	4.7 (.0001)	0.655
SEAMAN	0.574	7.6 (.0001)	65.09	5.7 (.0001)	0.594

* - probability of obtaining a t value as large as the one shown if the true slope or intercept is actually zero

TABLE 4.19. RESULTS OF REGRESSION ANALYSIS ON GAGE AND CORE MAT DENSITY RESULTS FOR THE ROCHESTER PROJECT (72 OBSERVATIONS).

GAGE	SLOPE	t-STATISTIC (PROB > $\|t\|$)*	INTERCEPT	t-STATISTIC (PROB > $\|t\|$)*	R-SQUARE
CPN	0.211	3.4 (.0011)	119.96	13.3 (.0001)	0.130
TROXLER	0.208	2.7 (.0087)	120.01	10.5 (.0001)	0.081
SEAMAN	0.233	3.3 (.0017)	115.70	10.8 (.0001)	0.120

* - probability of obtaining a t value as large as the one shown if the true slope or intercept is actually zero

TABLE 4.20. RESULTS OF REGRESSION ANALYSIS ON GAGE AND CORE JOINT DENSITY RESULTS FOR THE MORRISTOWN PROJECT (40 OBSERVATIONS).

GAGE	SLOPE	t-STATISTIC (PROB > |t|)*	INTERCEPT	t-STATISTIC (PROB > |t|)*	R-SQUARE
CPN	0.389	5.0 (.0001)	92.49	8.7 (.0001)	0.378
TROXLER	0.466	5.6 (.0001)	80.93	7.0 (.0001)	0.436
SEAMAN	0.384	6.5 (.0001)	92.12	11.2 (.0001)	0.515

* - probability of obtaining a t value as large as the one shown if the true slope or intercept is actually zero

TABLE 4.21. RESULTS OF REGRESSION ANALYSIS ON GAGE AND CORE JOINT DENSITY RESULTS FOR THE ROCHESTER PROJECT (72 OBSERVATIONS).

GAGE	SLOPE	t-STATISTIC (PROB > |t|)*	INTERCEPT	t-STATISTIC (PROB > |t|)*	R-SQUARE
CPN	0.702	9.6 (.0001)	44.52	4.3 (.0001)	0.562
TROXLER	0.743	10.1 (.0001)	37.13	3.5 (.0008)	0.585
SEAMAN	0.591	6.9 (.0001)	57.80	4.7 (.069)	0.398

* - probability of obtaining a t value as large as the one shown if the true slope or intercept is actually zero

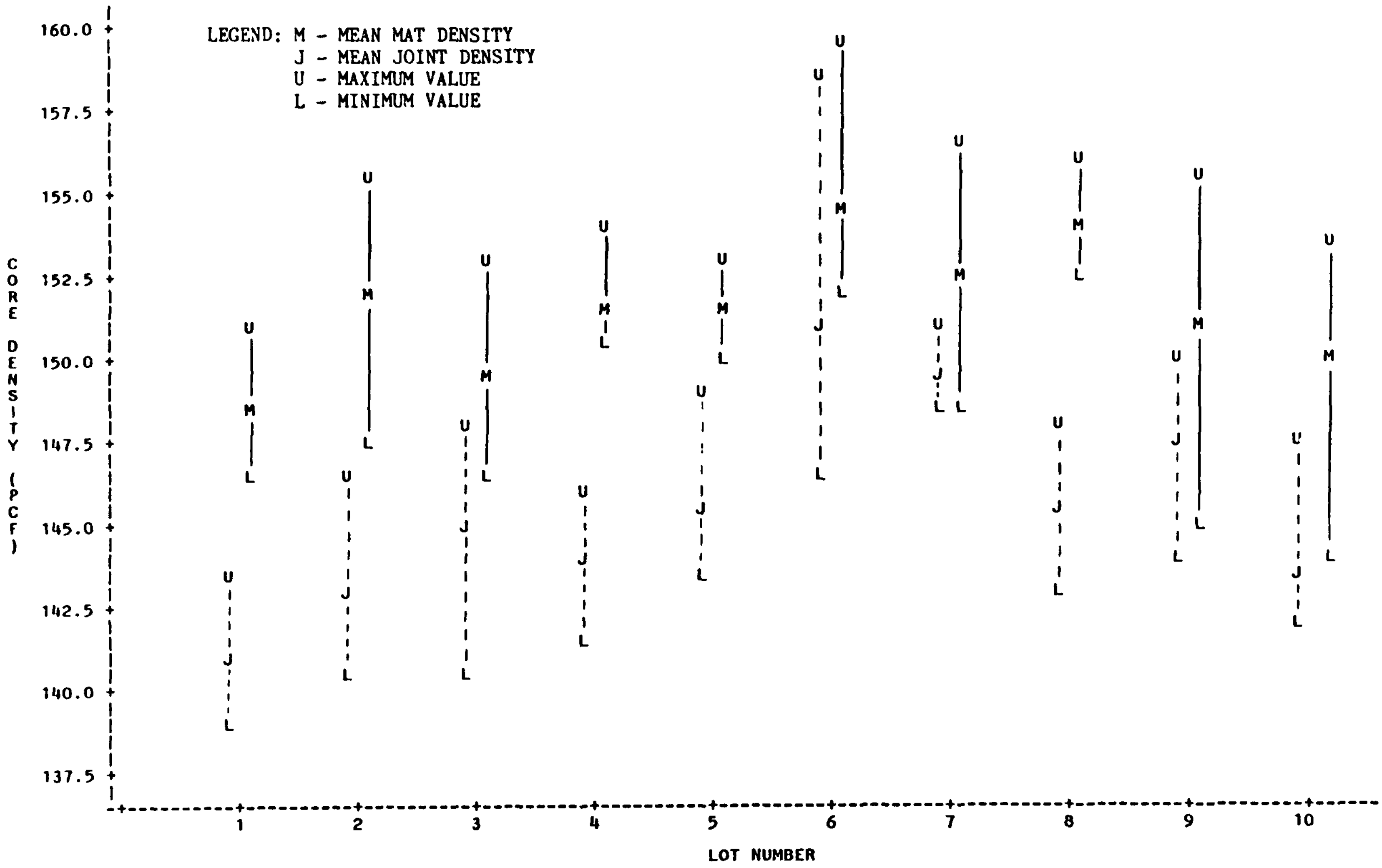

FIGURE 4.1. PLOT OF CORE DENSITY RESULTS FOR THE MORRISTOWN PROJECT

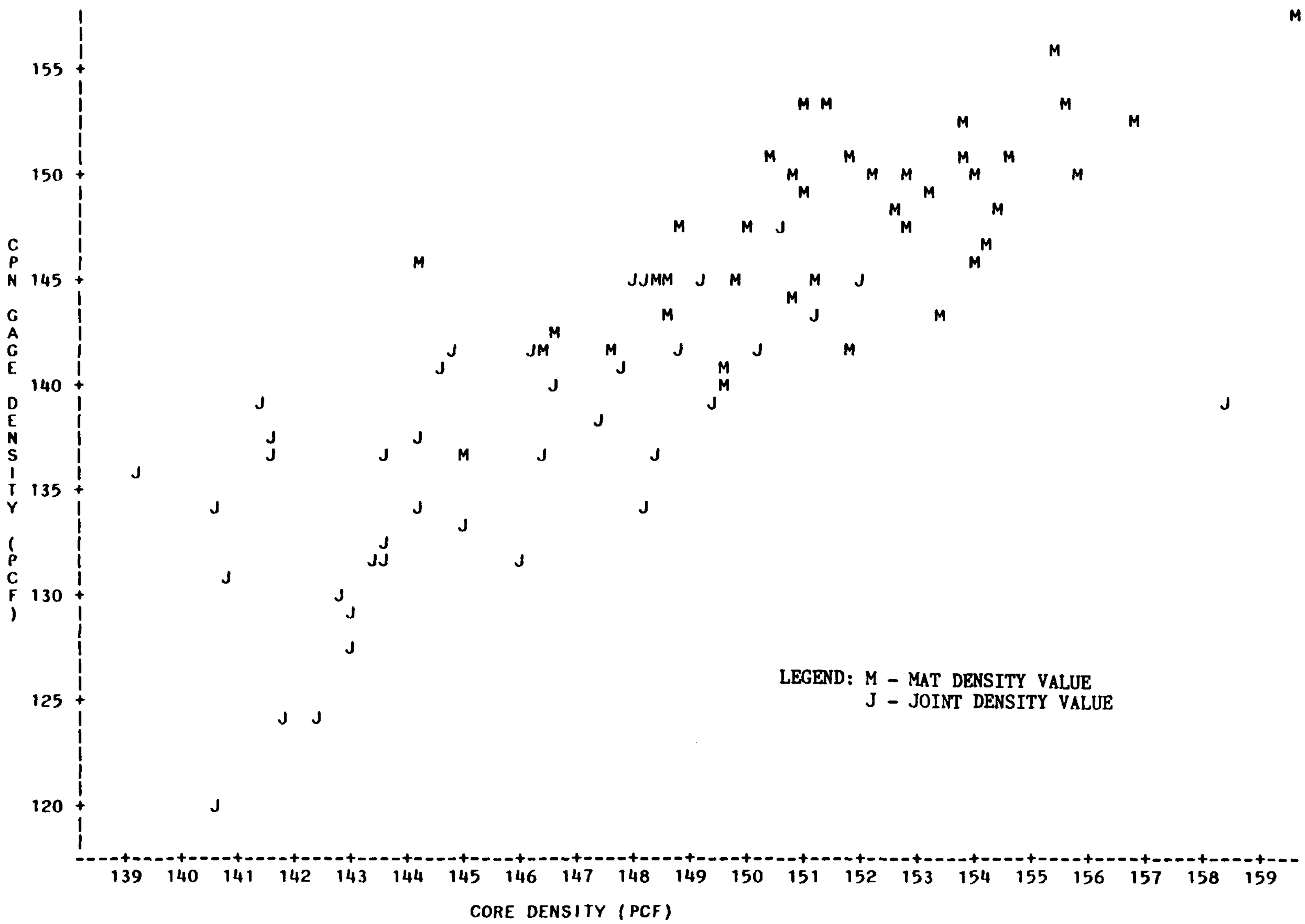

FIGURE 4.15. PLOT OF CPN GAGE RESULTS VERSUS CORE DENSITY RESULTS FOR THE MORRISTOWN PROJECT

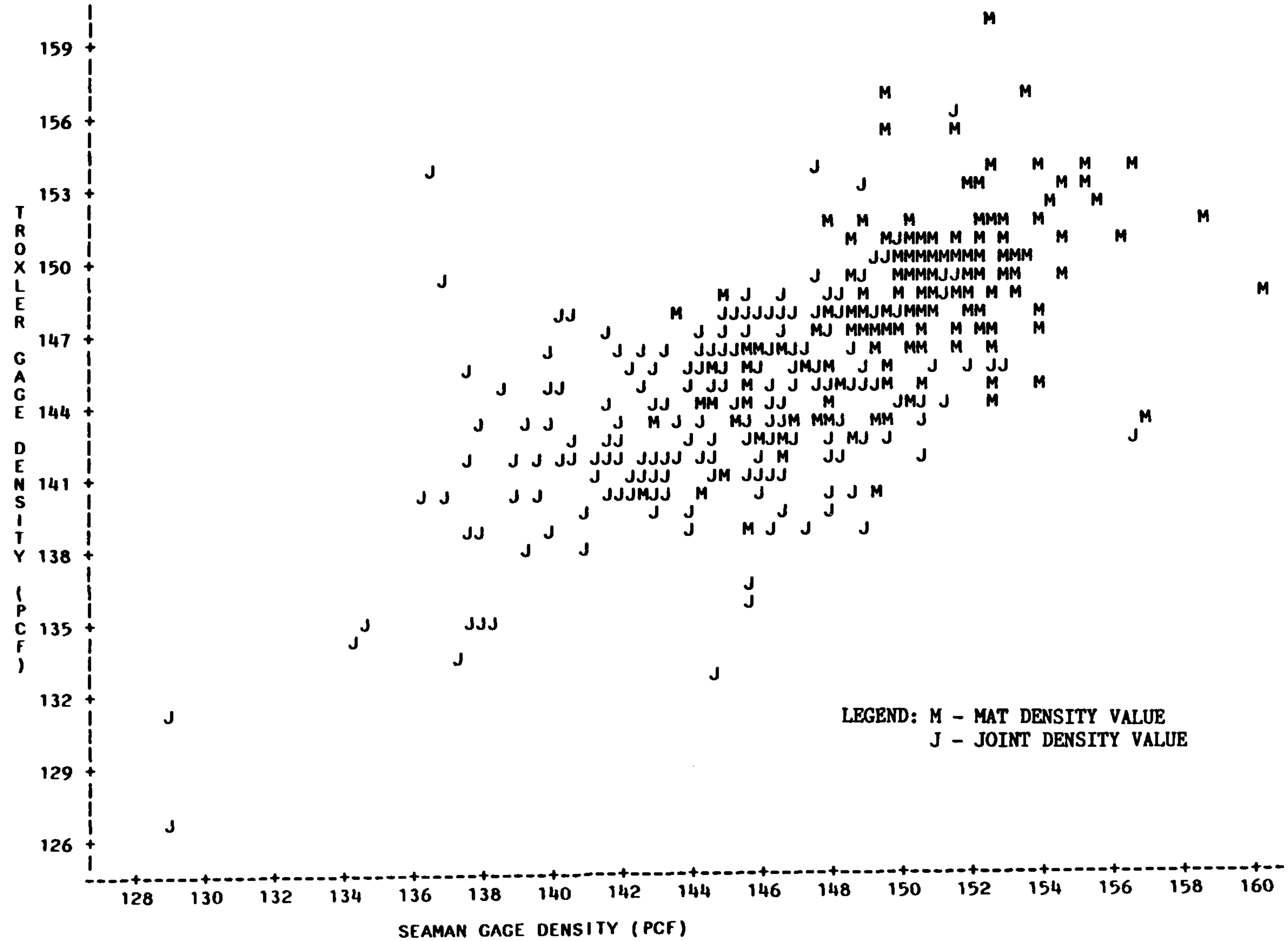

FIGURE 4.14. PLOT OF TROXLER VERSUS SEAMAN GAGE DENSITY RESULTS FOR THE ROCHESTER PROJECT

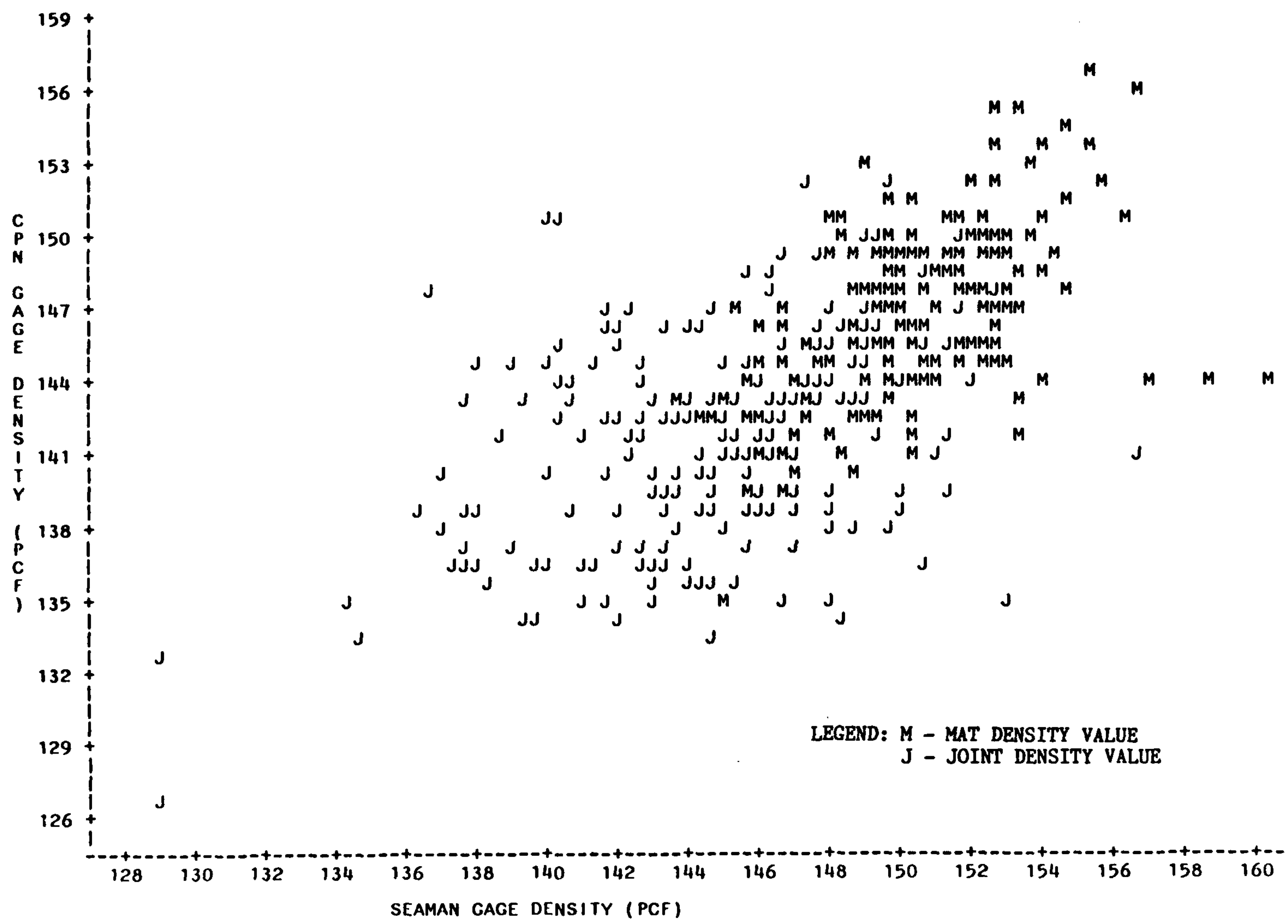

FIGURE 4.13. PLOT OF CPN VERSUS SEAMAN GAGE DENSITY RESULTS FOR THE ROCHESTER PROJECT

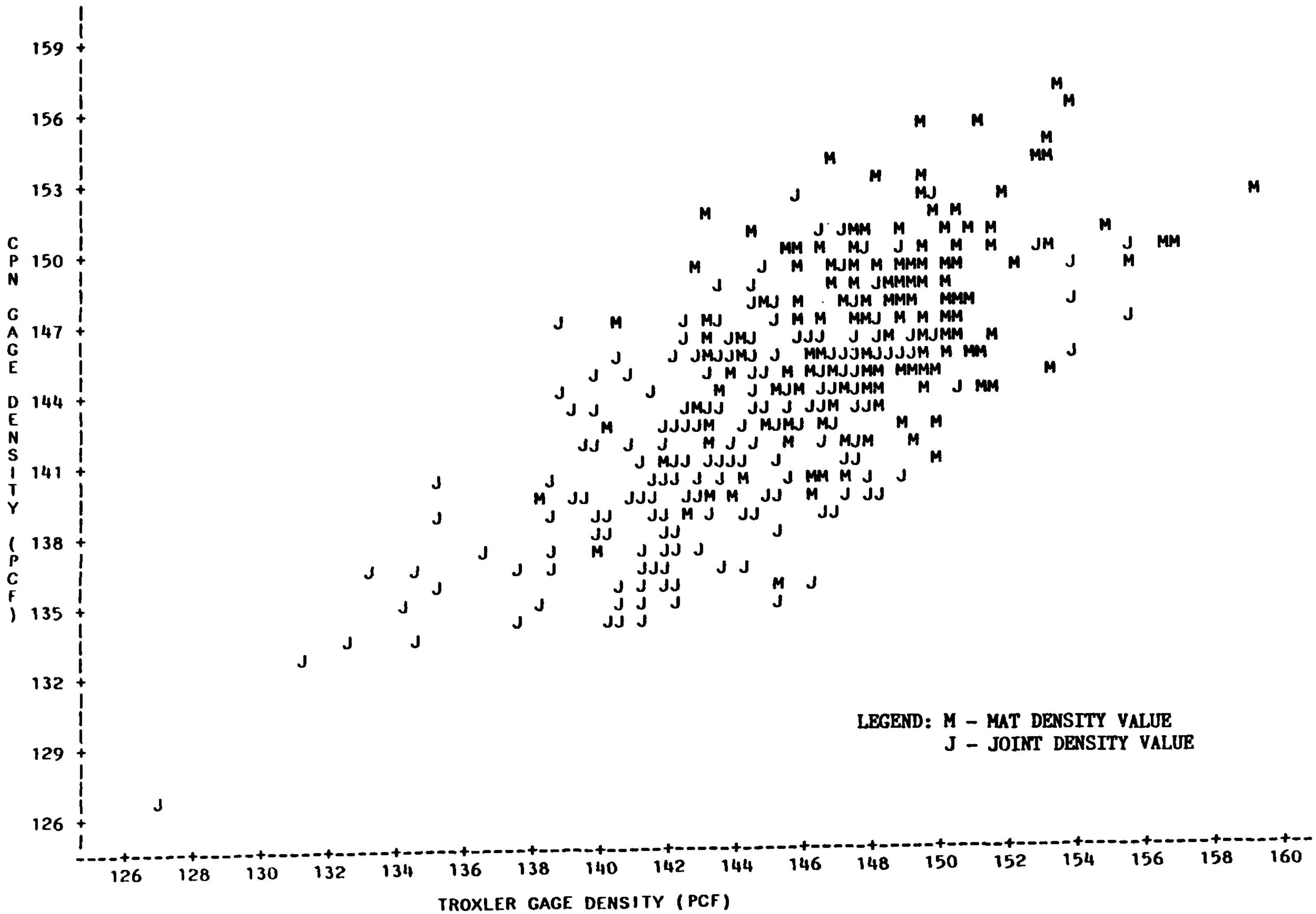

FIGURE 4.12. PLOT OF CPN VERSUS TROXLER GAGE DENSITY RESULTS FOR THE ROCHESTER PROJECT

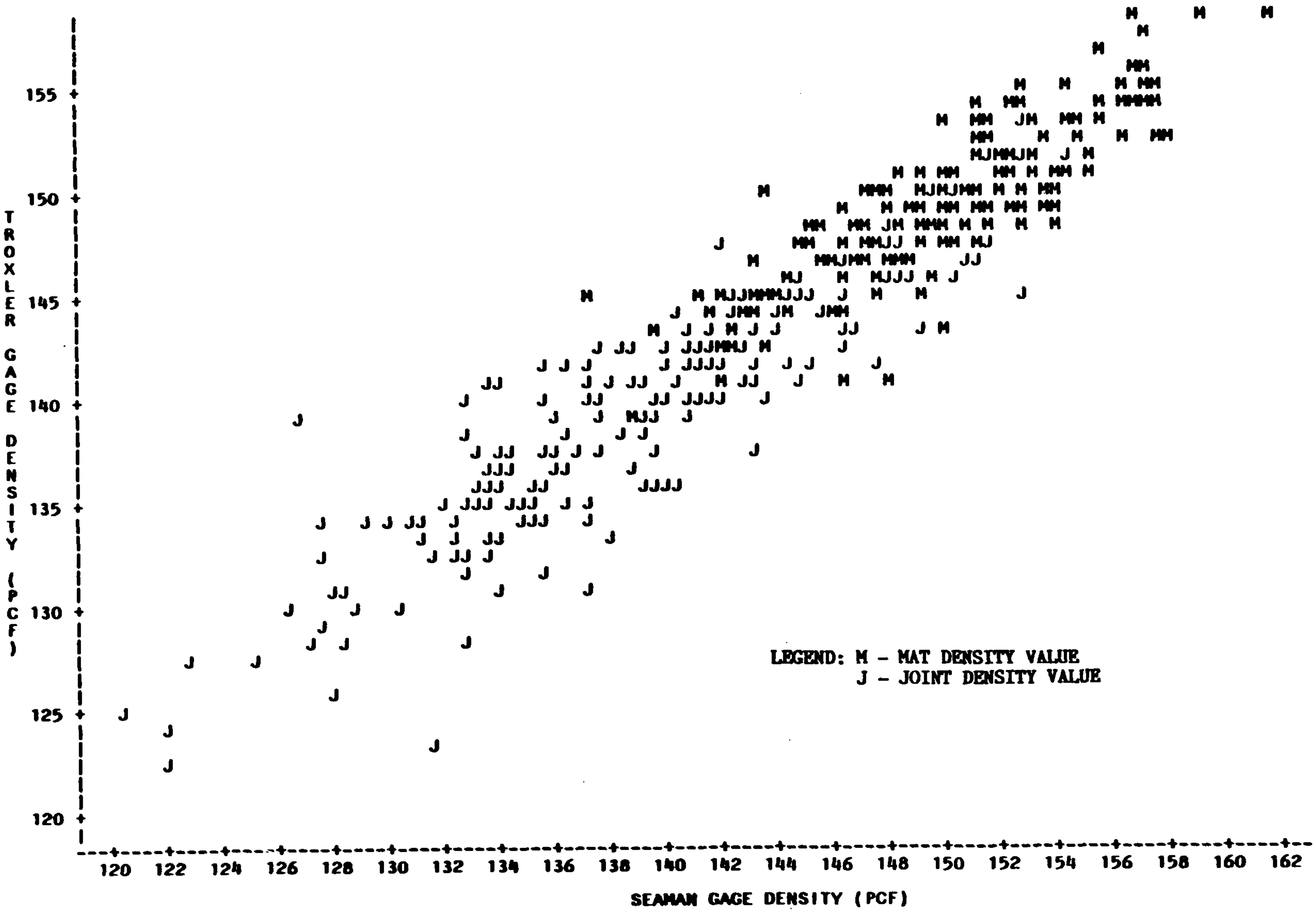

FIGURE 4.11. PLOT OF TROXLER VERSUS SEAMAN GAGE DENSITY RESULTS FOR THE MORRISTOWN PROJECT

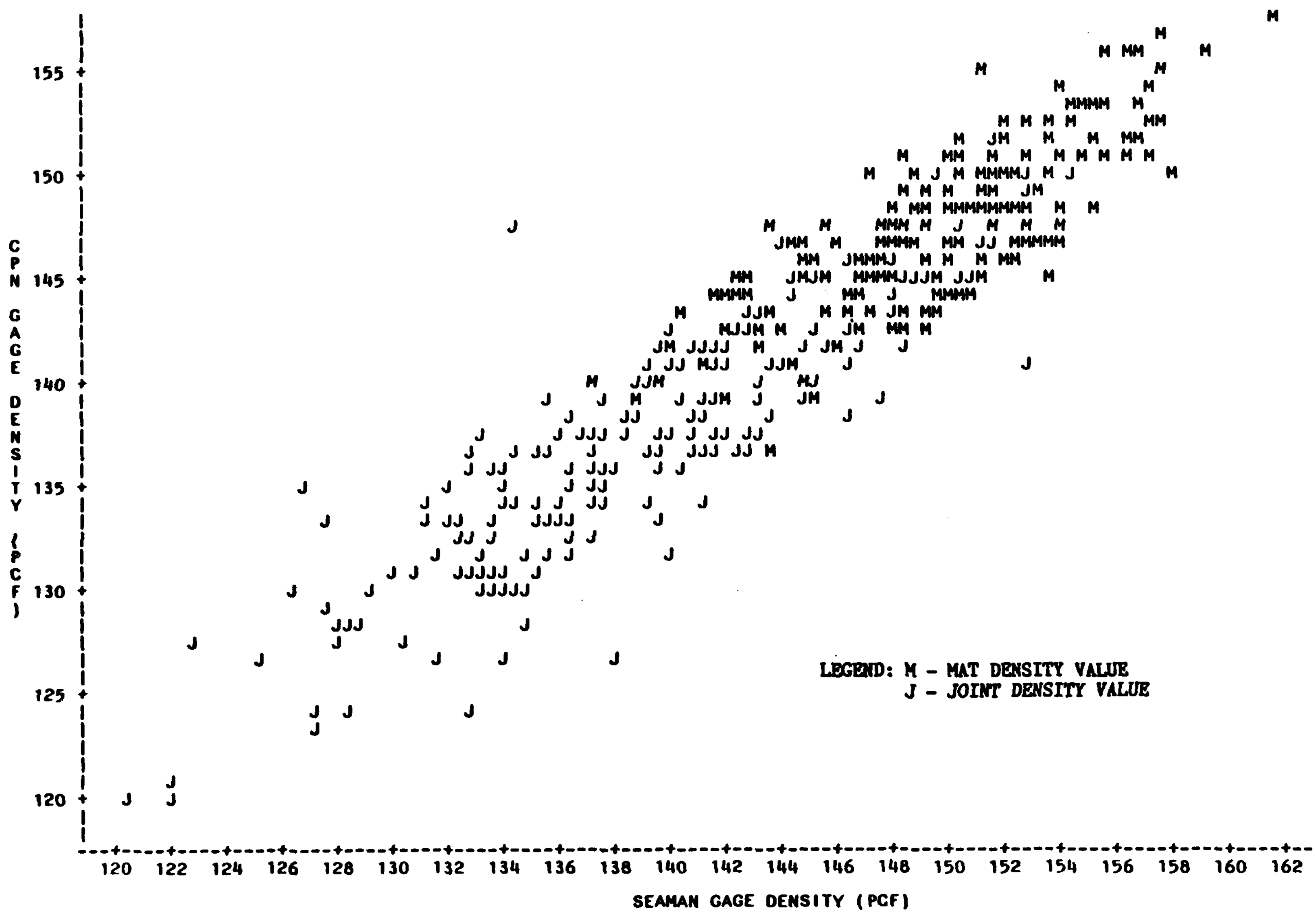

FIGURE 4.10. PLOT OF CPN VERSUS SEAMAN GAGE DENSITY RESULTS FOR THE MORRISTOWN PROJECT

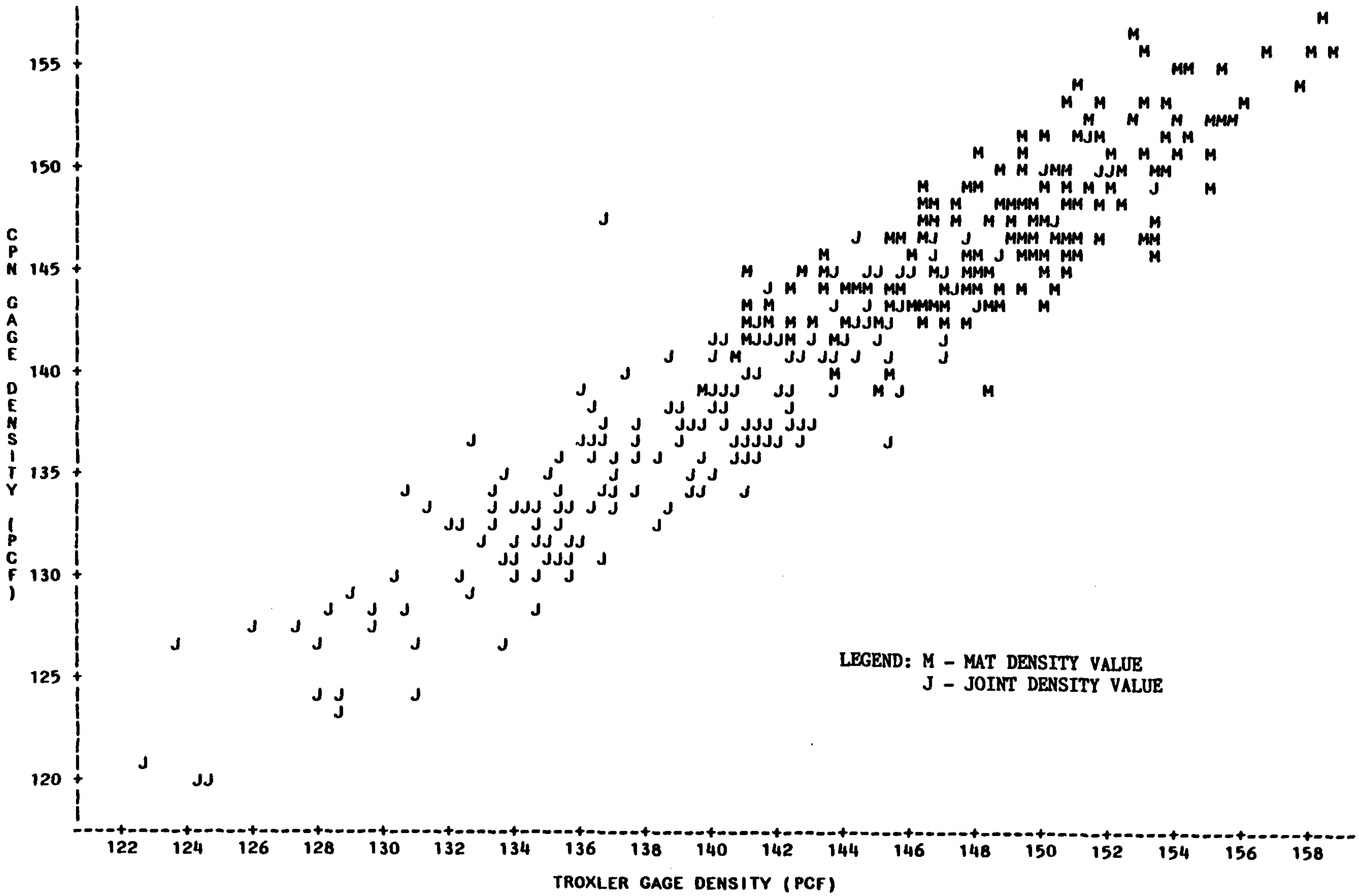

FIGURE 4.9. PLOT OF CPN VERSUS TROXLER GAGE DENSITY RESULTS FOR THE MORRISTOWN PROJECT

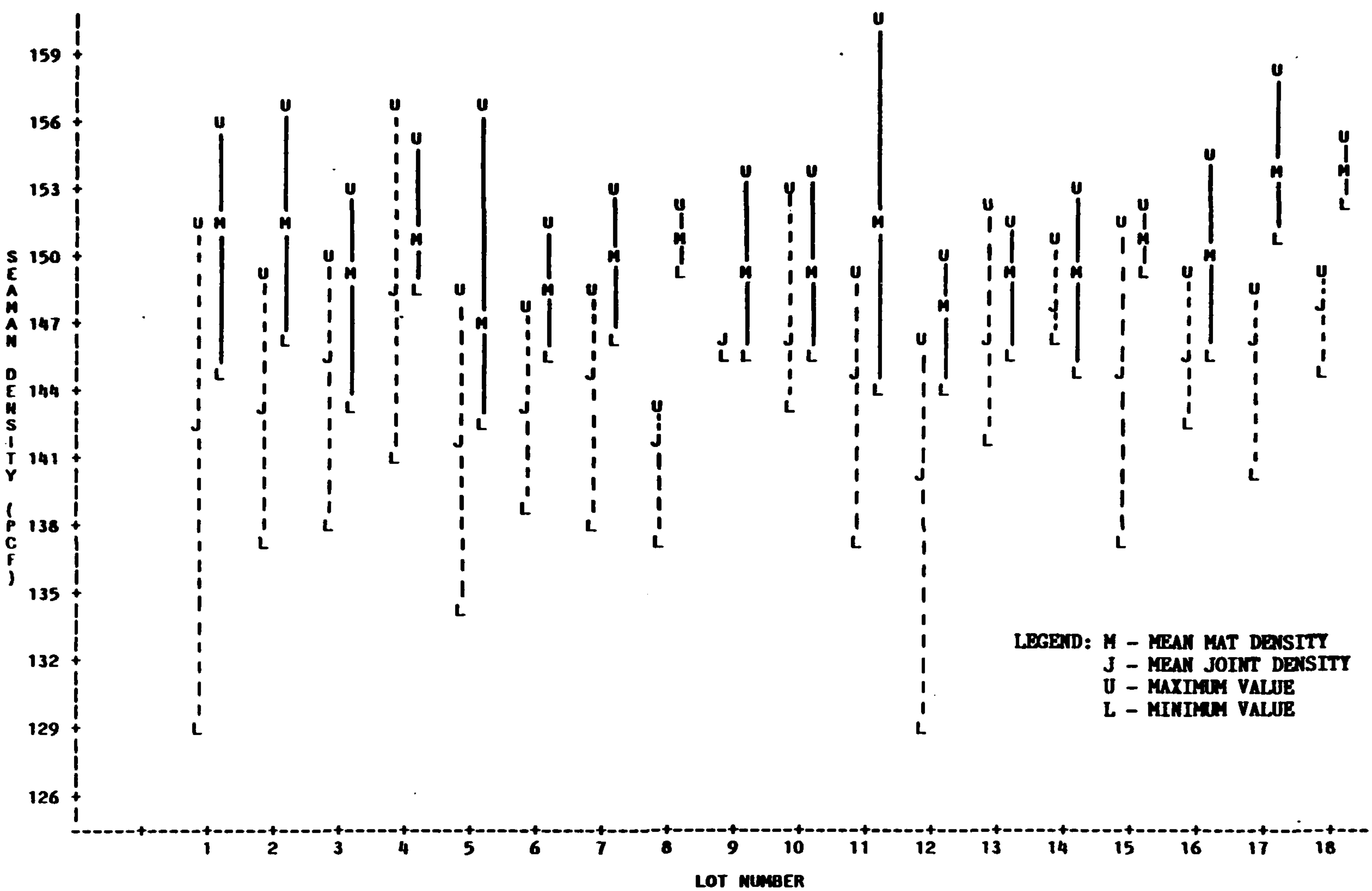

FIGURE 4.8. PLOT OF SEAMAN GAGE DENSITY RESULTS FOR THE ROCHESTER PROJECT

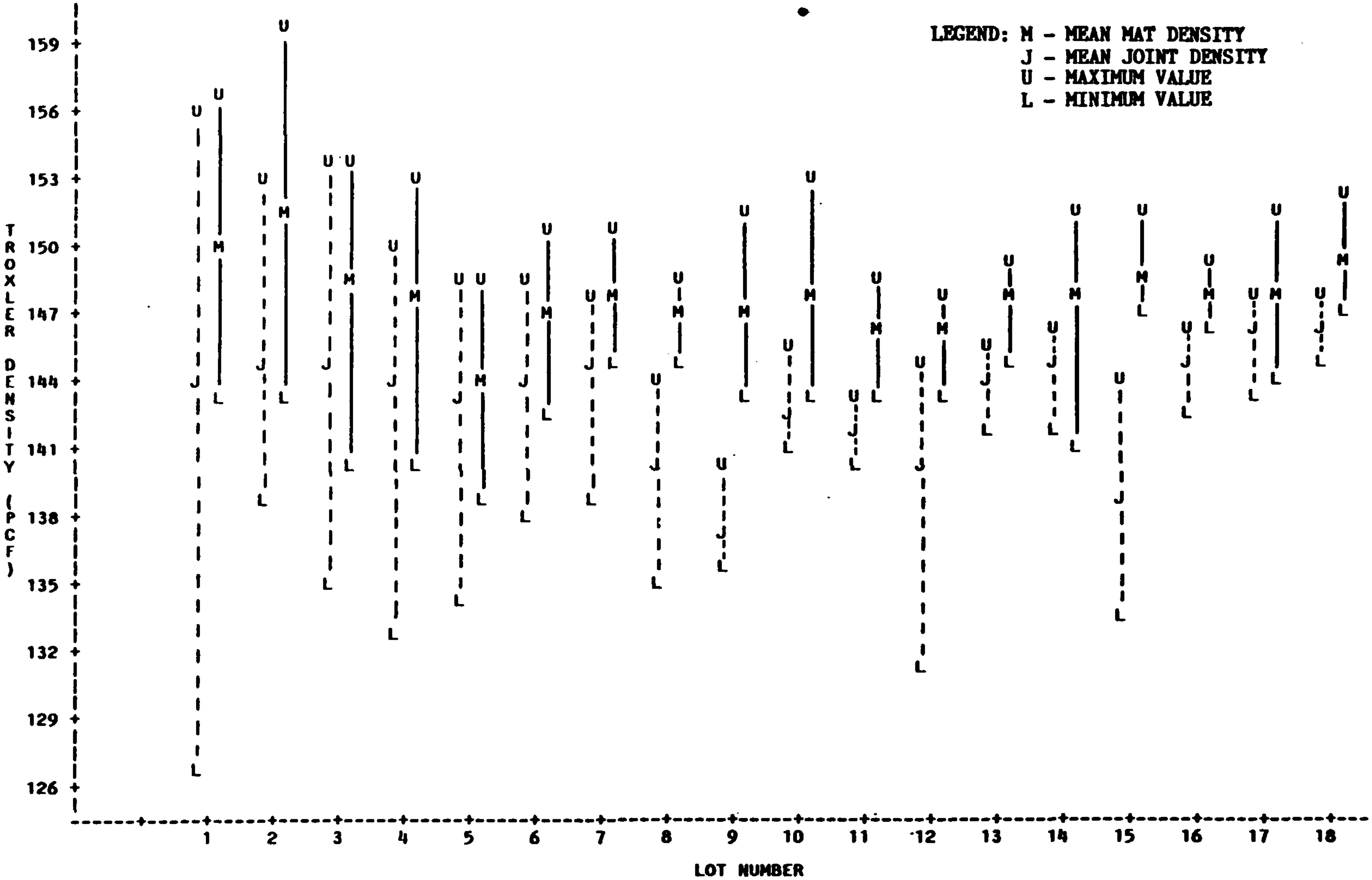

FIGURE 4.7. PLOT OF TROXLER GAGE DENSITY RESULTS FOR THE ROCHESTER PROJECT

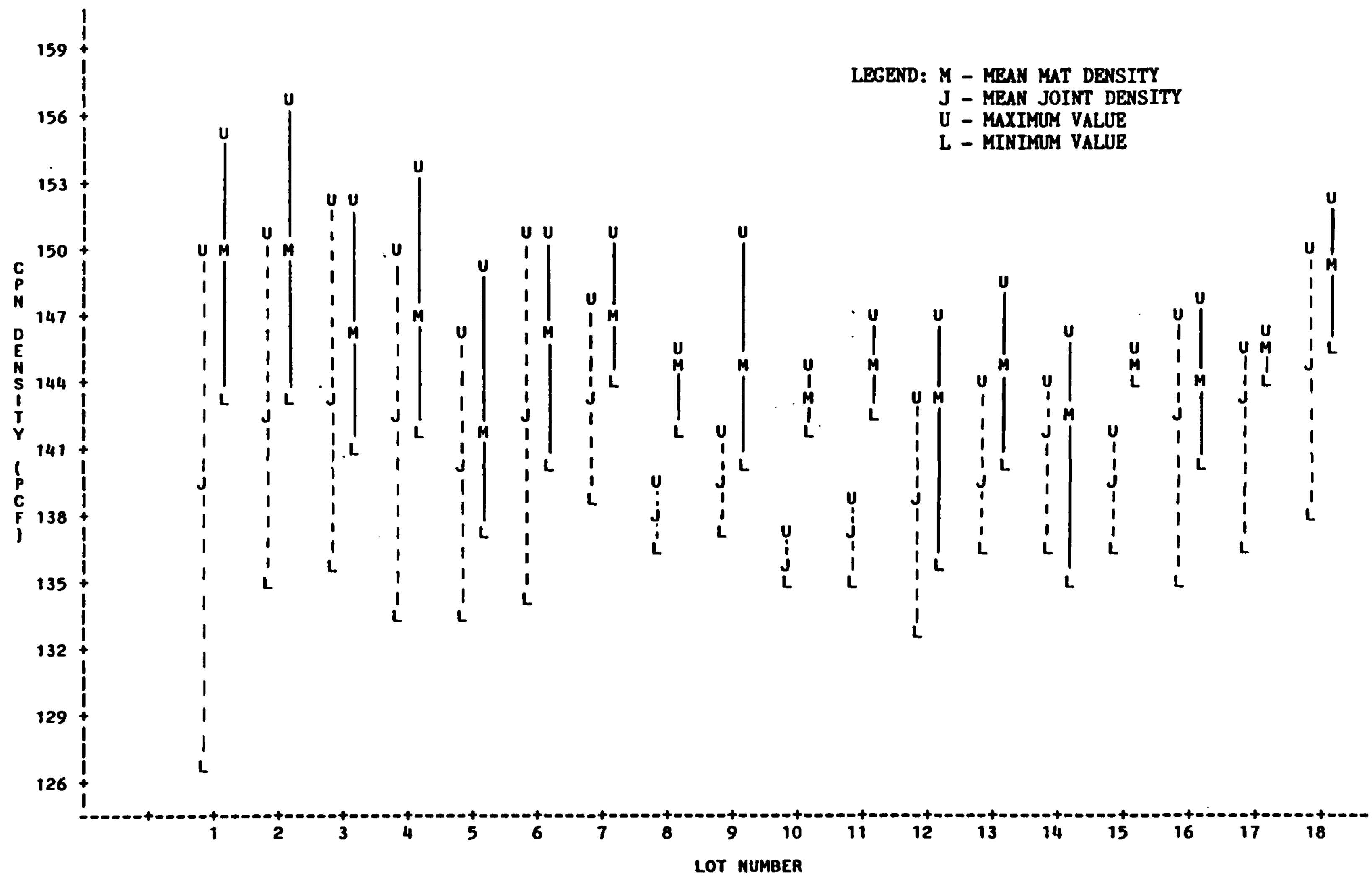

FIGURE 4.6. PLOT OF CPN GAGE DENSITY RESULTS FOR THE ROCHESTER PROJECT

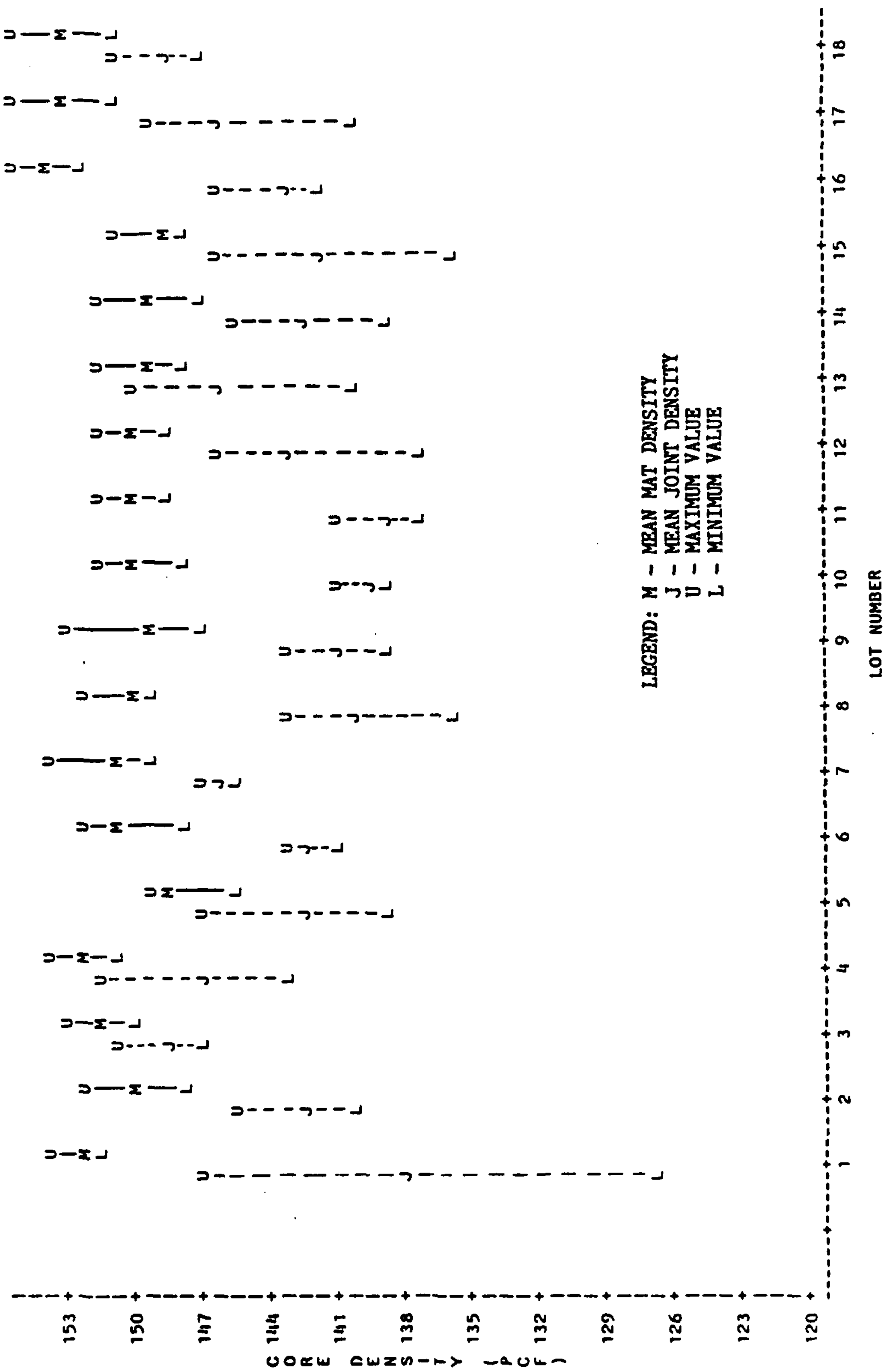

FIGURE 4.5. PLOT OF CORE DENSITY RESULTS FOR THE ROCHESTER PROJECT

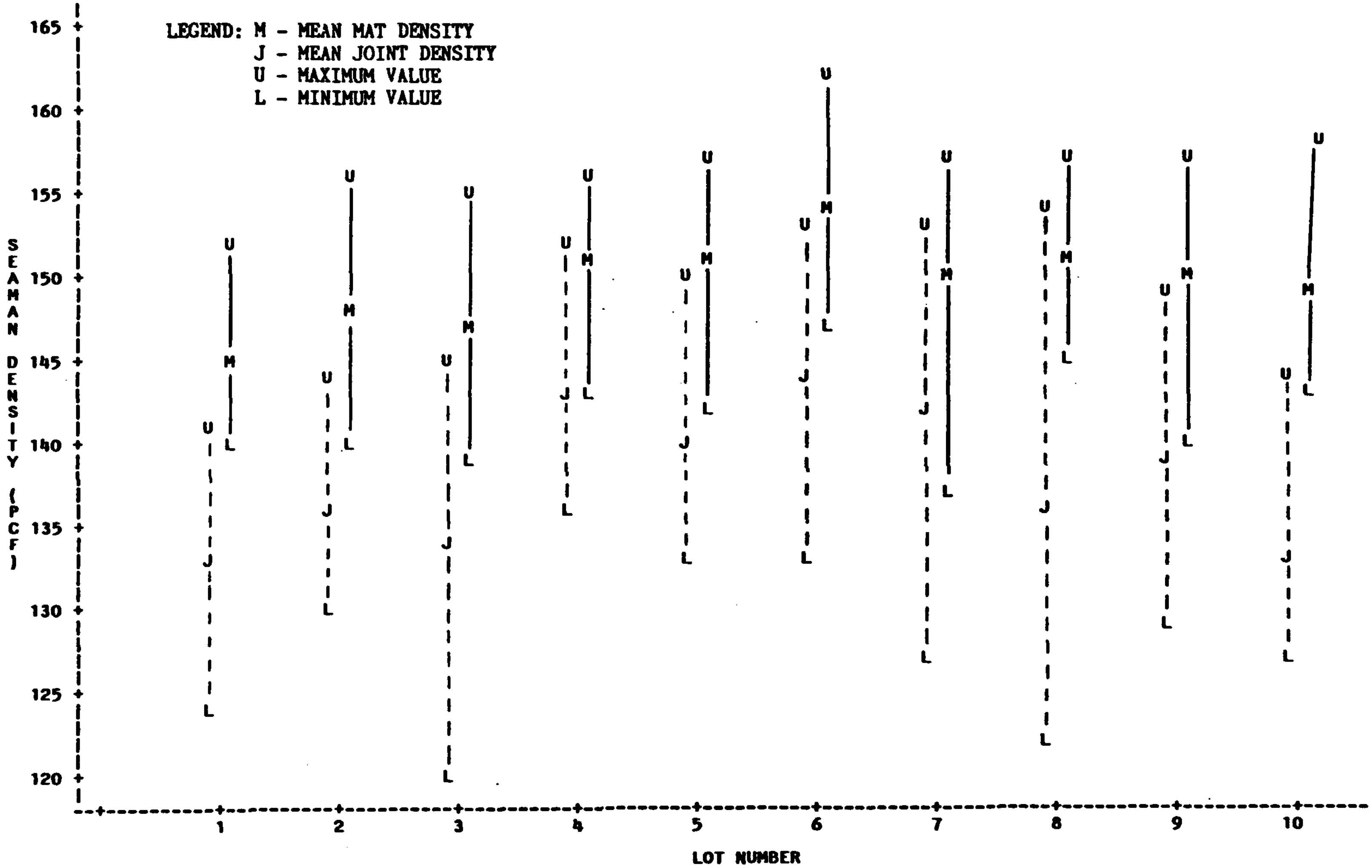

FIGURE 4.4. PLOT OF SEAMAN GAGE DENSITY RESULTS FOR THE MORRISTOWN PROJECT

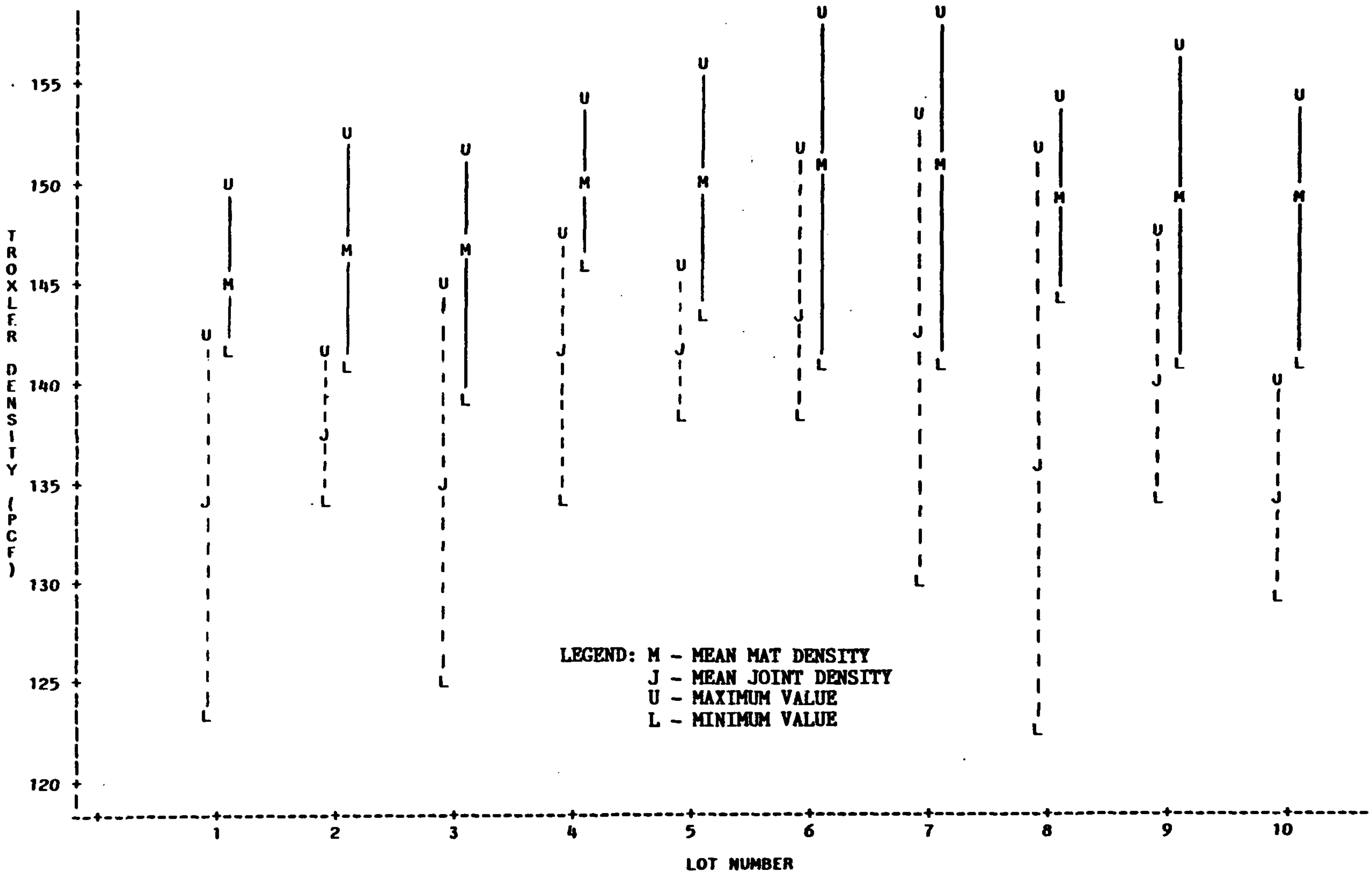

FIGURE 4.3. PLOT OF TROXLER GAGE DENSITY RESULTS FOR THE MORRISTOWN PROJECT

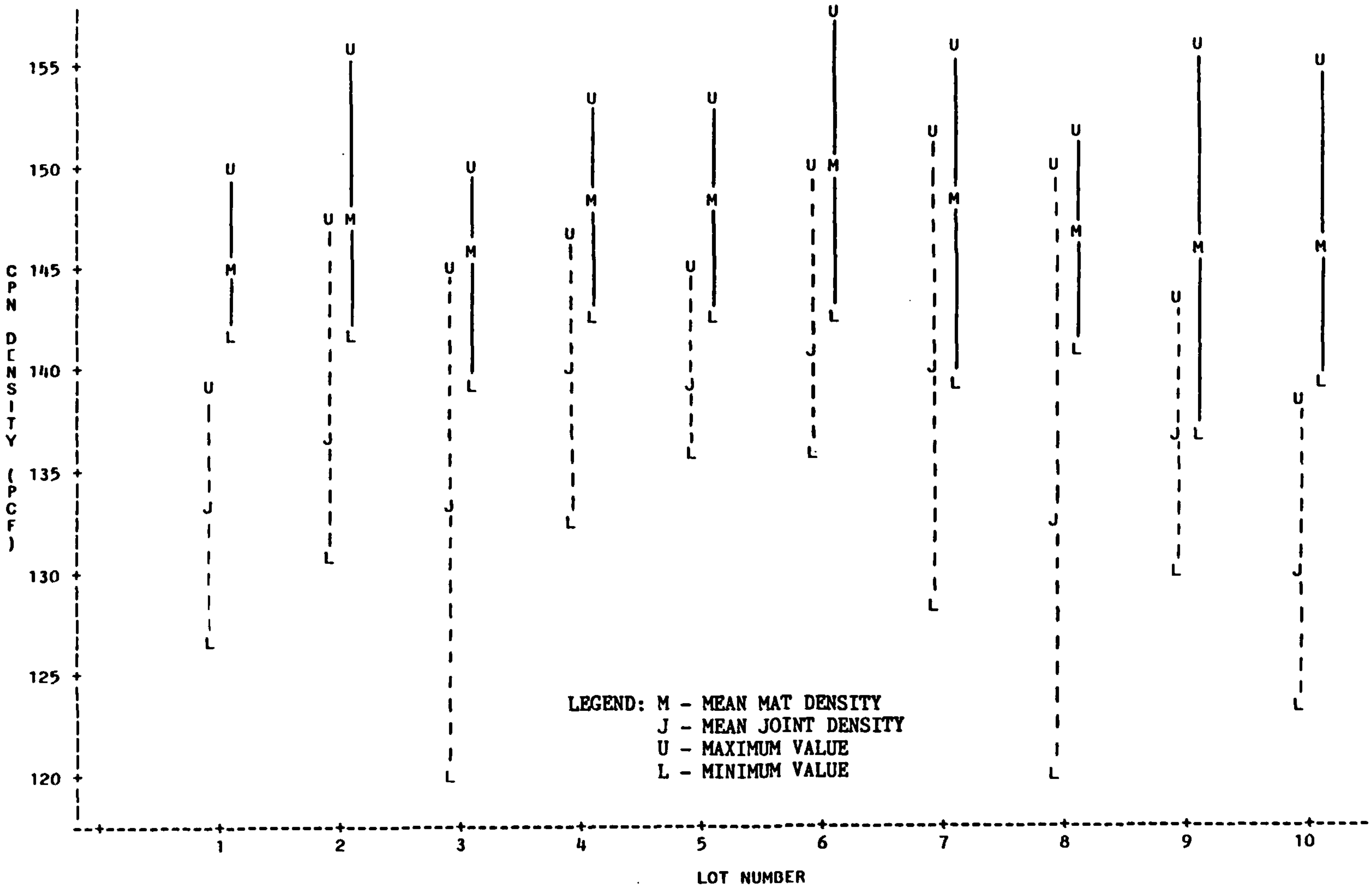

FIGURE 4.2. PLOT OF CPN GAGE DENSITY RESULTS FOR THE MORRISTOWN PROJECT

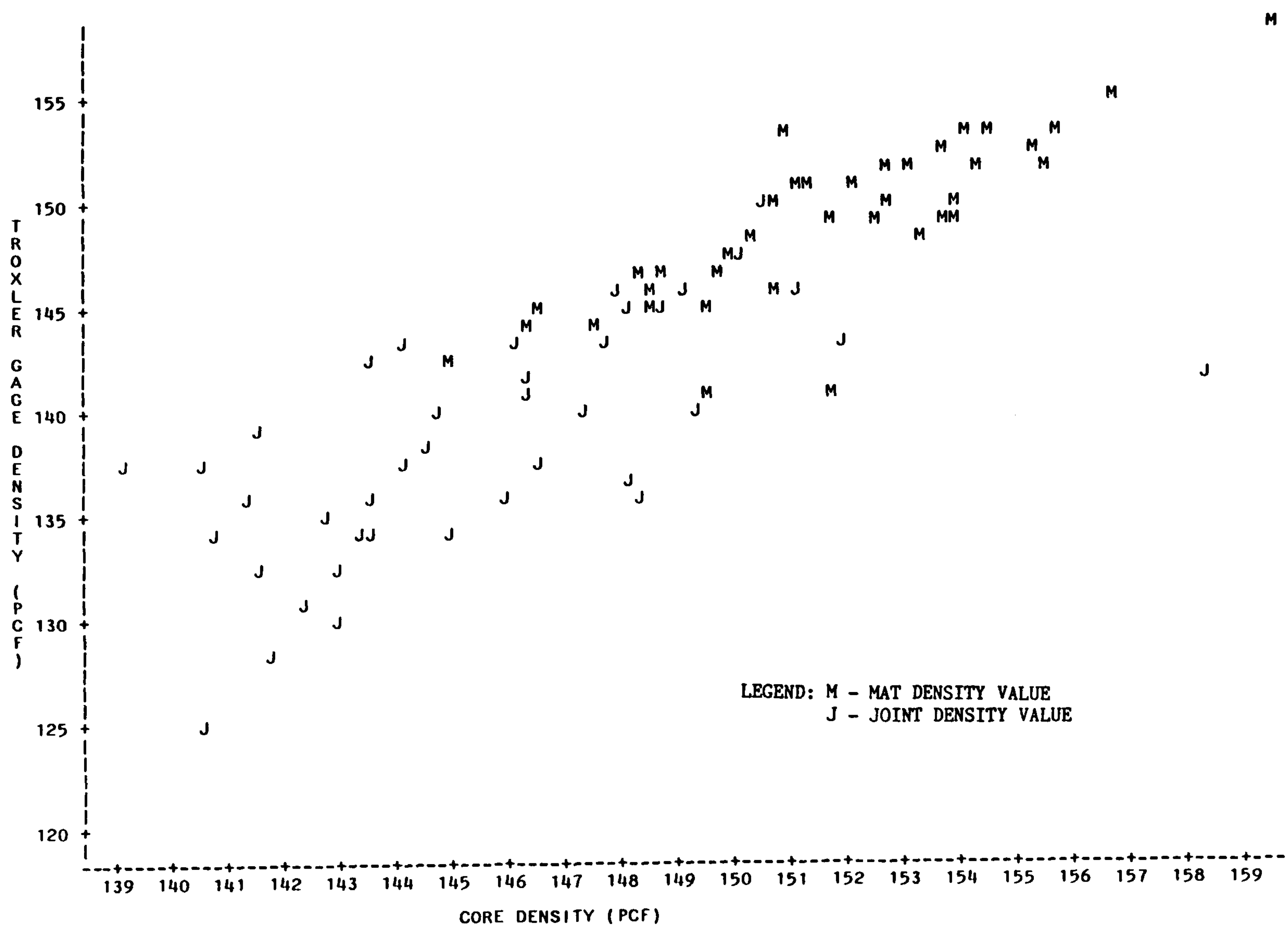

FIGURE 4.16. PLOT OF TROXLER GAGE RESULTS VERSUS CORE DENSITY RESULTS FOR THE MORRISTOWN PROJECT

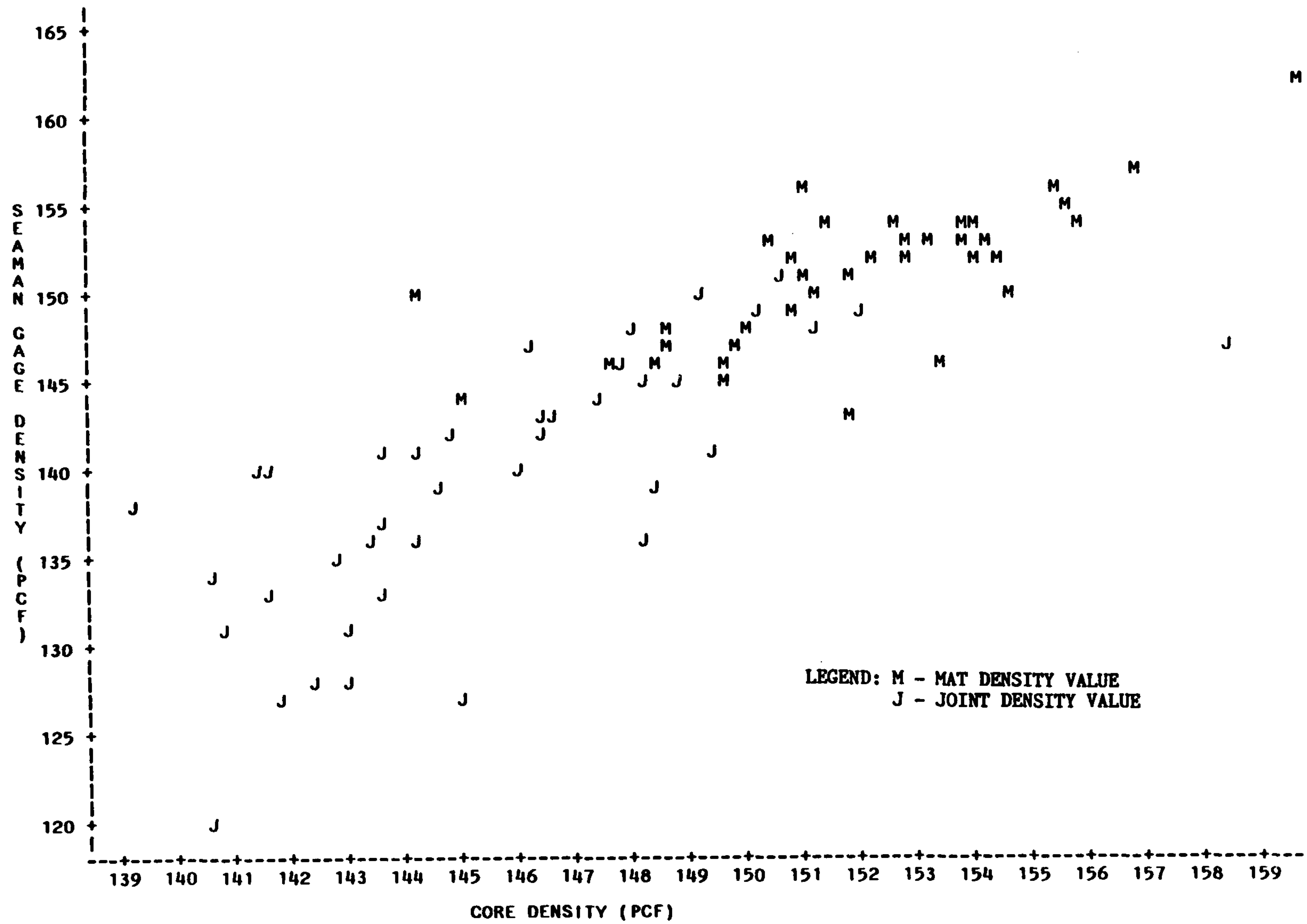

FIGURE 4.17. PLOT OF SEAMAN GAGE RESULTS VERSUS CORE DENSITY RESULTS FOR THE MORRISTOWN PROJECT

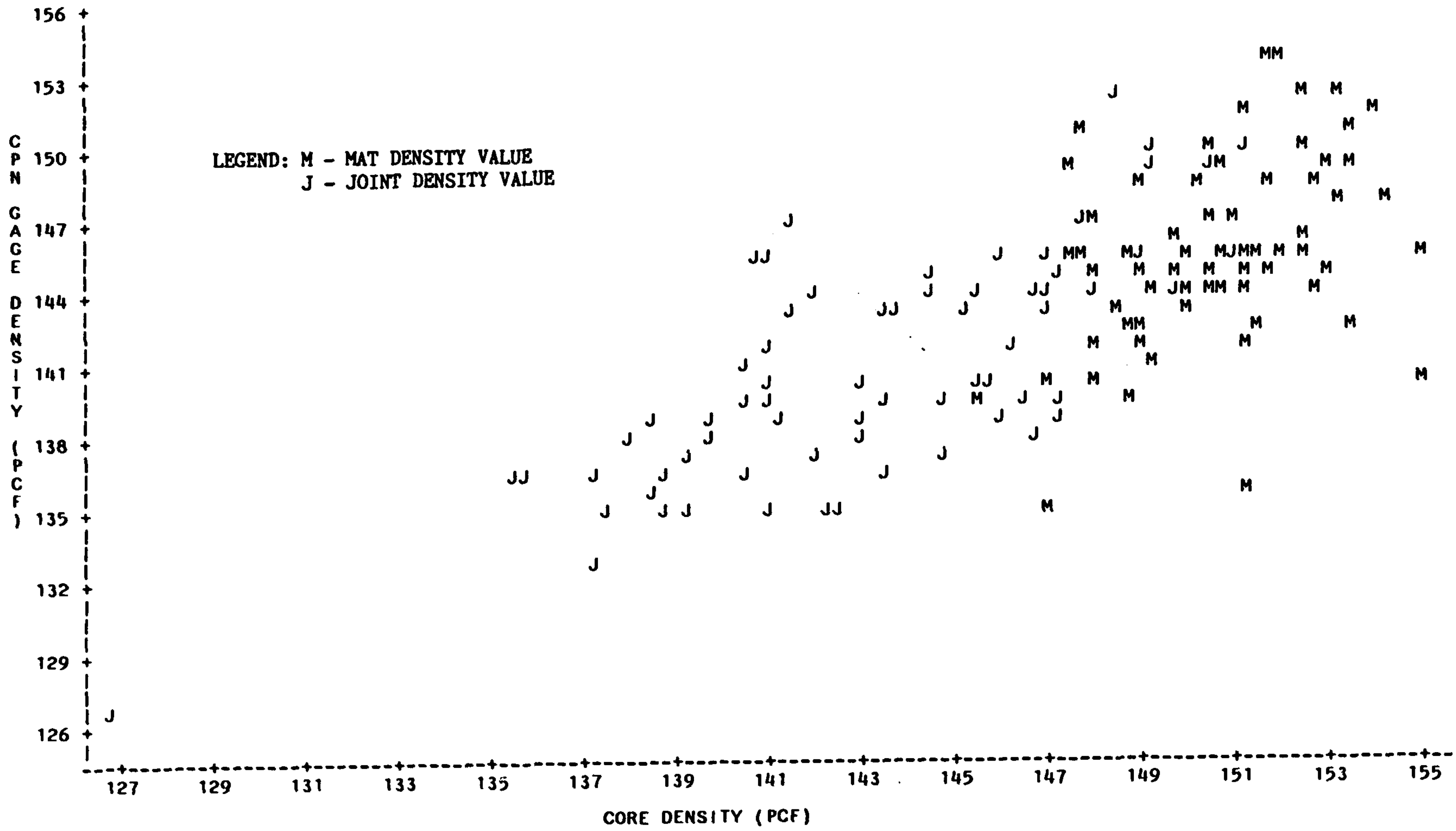

FIGURE 4.18. PLOT OF CPN GAGE RESULTS VERSUS CORE DENSITY RESULTS FOR THE ROCHESTER PROJECT

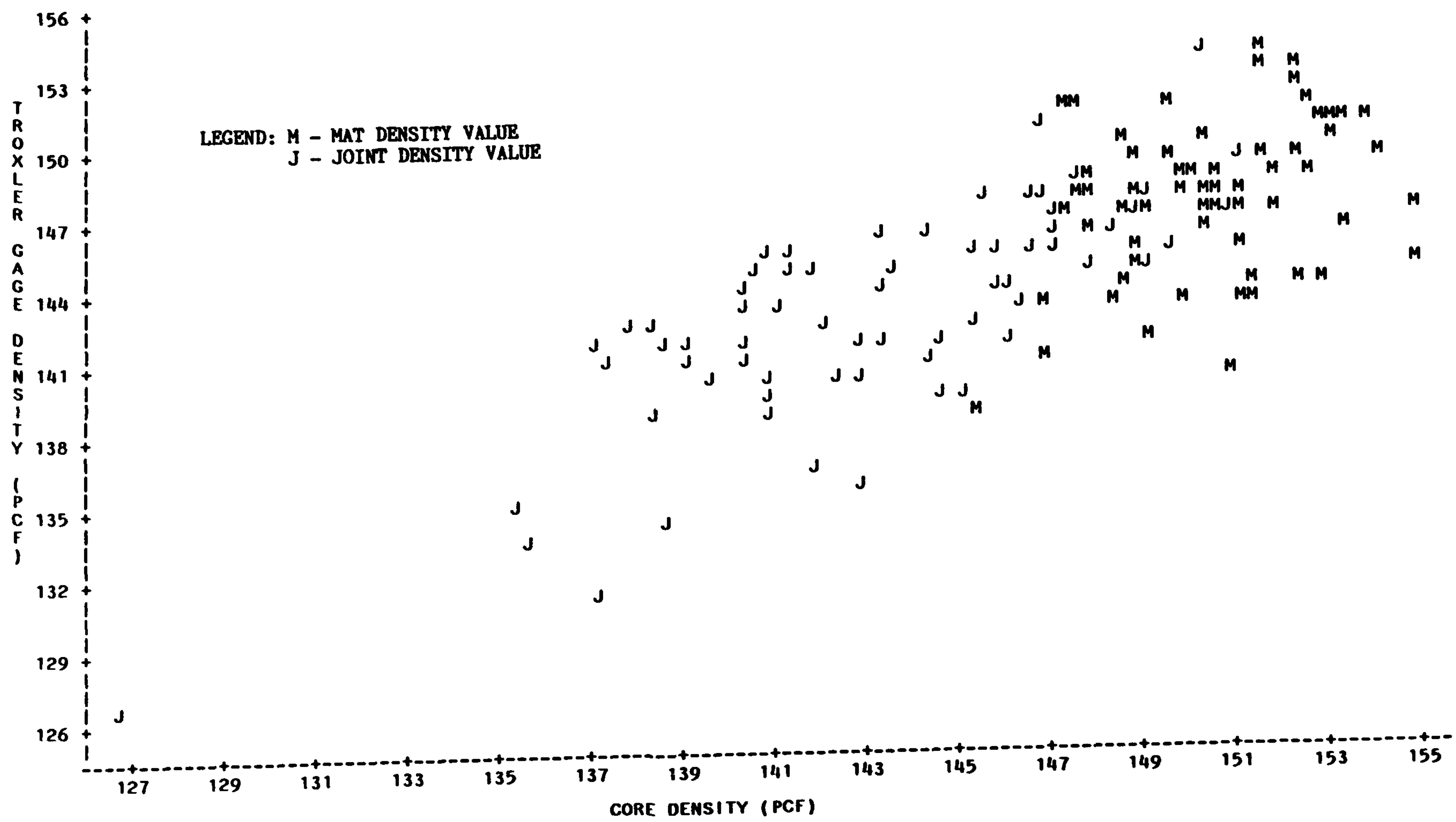

FIGURE 4.19. PLOT OF TROXLER GAGE RESULTS VERSUS CORE DENSITY RESULTS FOR THE ROCHESTER PROJECT

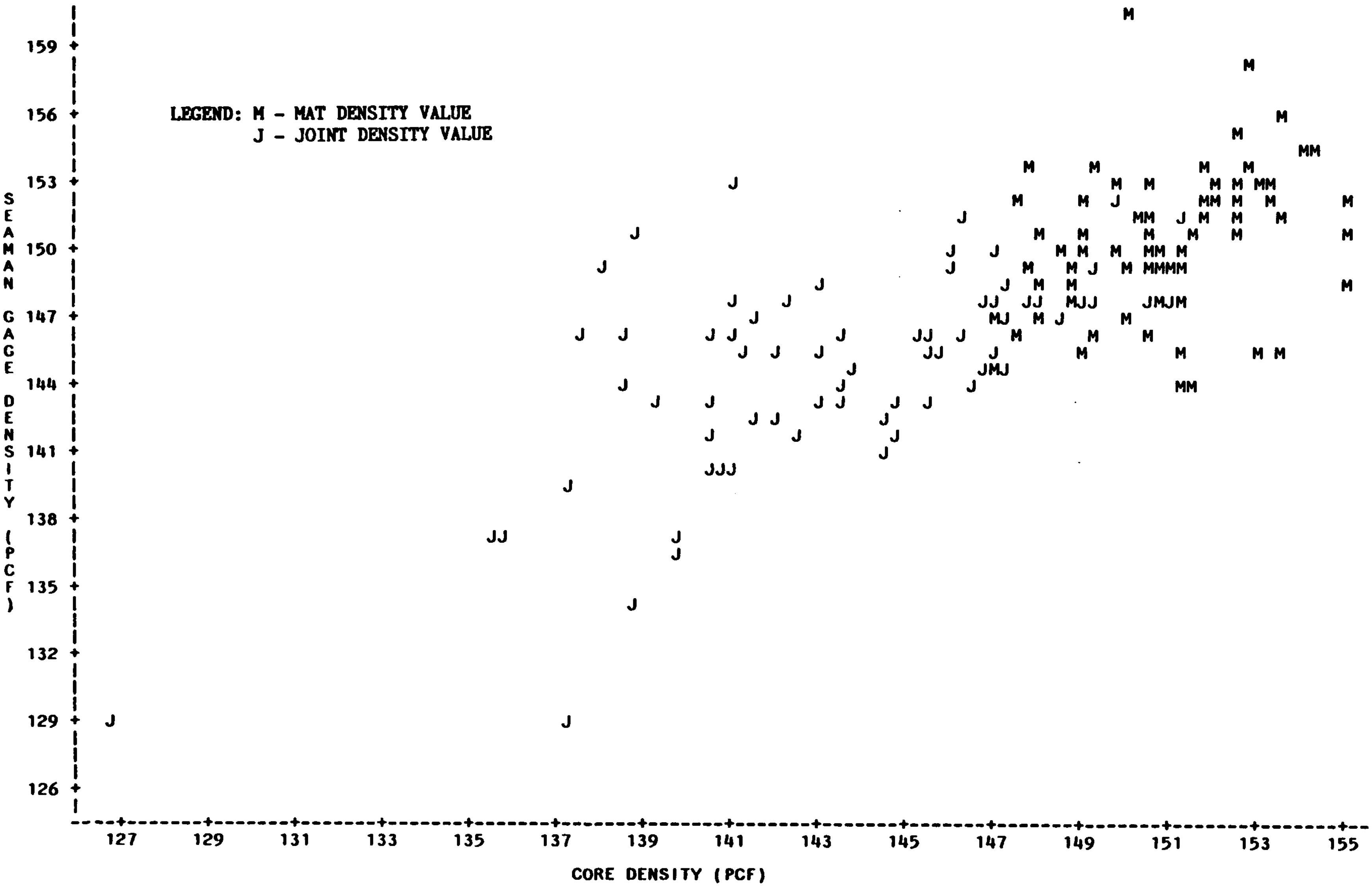

FIGURE 4.20. PLOT OF SEAMAN GAGE RESULTS VERSUS CORE DENSITY RESULTS FOR THE ROCHESTER PROJECT

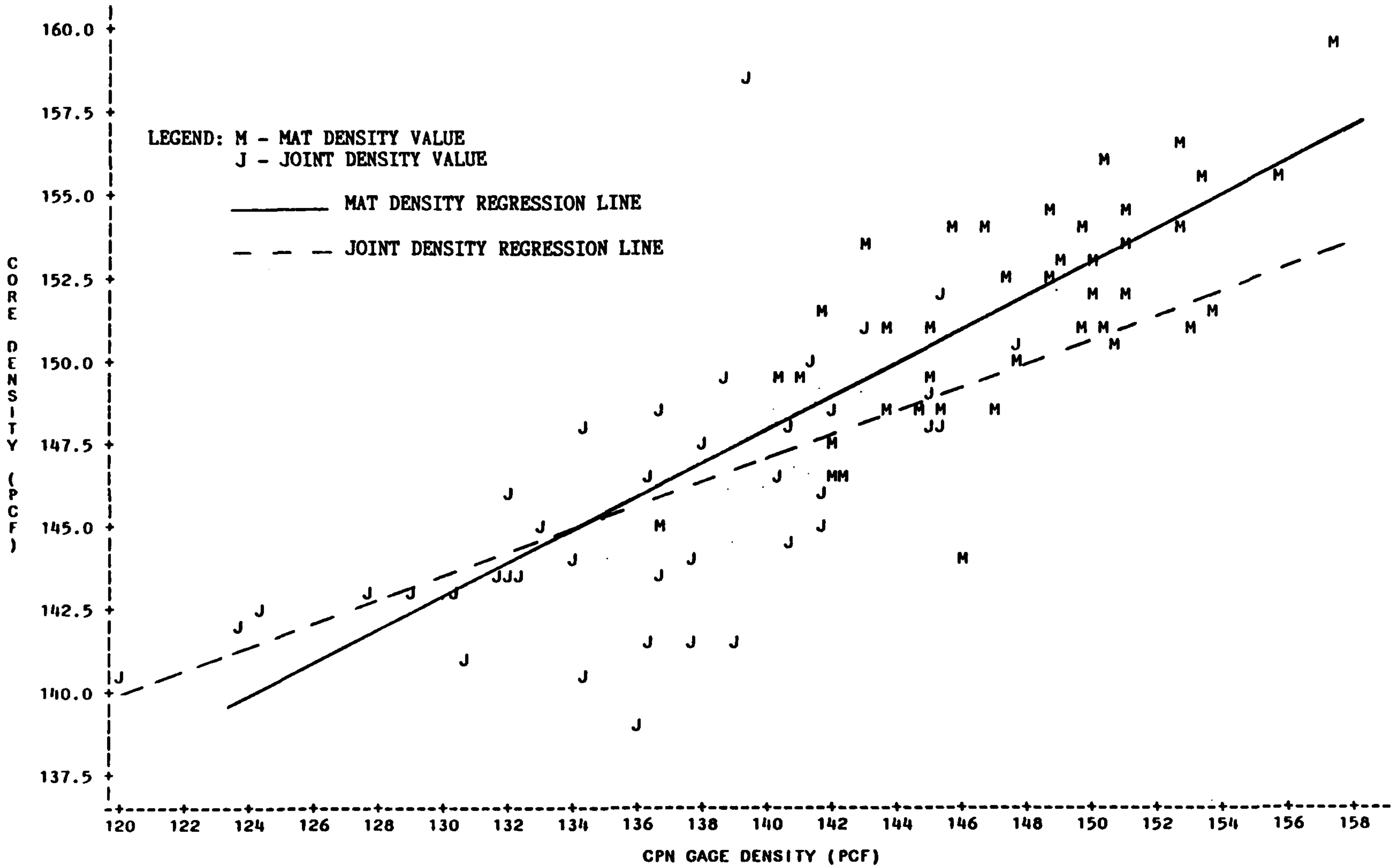

FIGURE 4.21. PLOT OF JOINT AND MAT DENSITY REGRESSION LINES FOR CORE DENSITY VERSUS CPN GAGE DENSITY FOR THE MORRISTOWN PROJECT

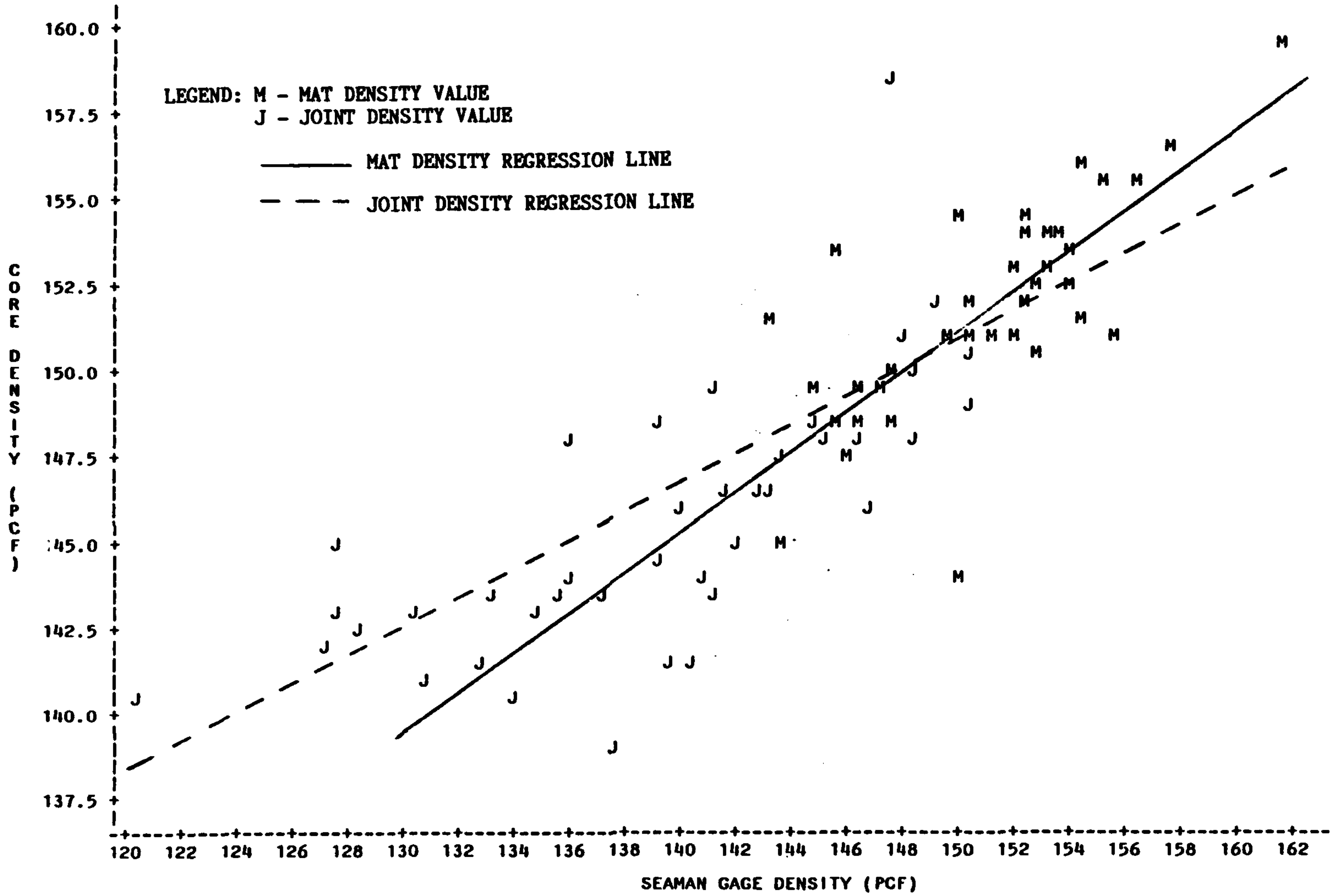

FIGURE 4.22. PLOT OF JOINT AND MAT DENSITY REGRESSION LINES FOR CORE DENSITY VERSUS SEAMAN GAGE DENSITY FOR THE MORRISTOWN PROJECT

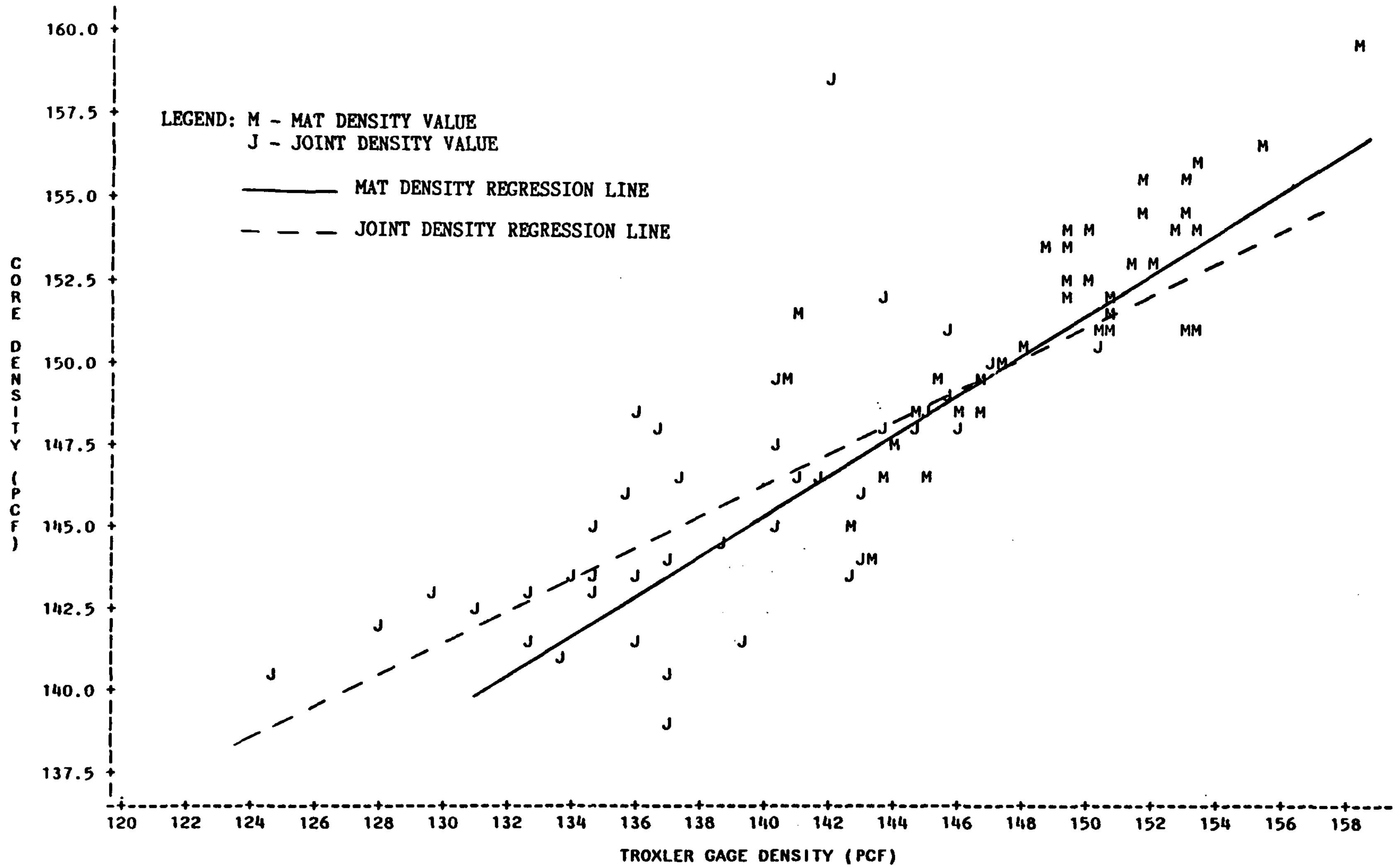

FIGURE 4.23. PLOT OF JOINT AND MAT DENSITY REGRESSION LINES FOR CORE DENSITY VERSUS TROXLER GAGE DENSITY FOR THE MORRISTOWN PROJECT

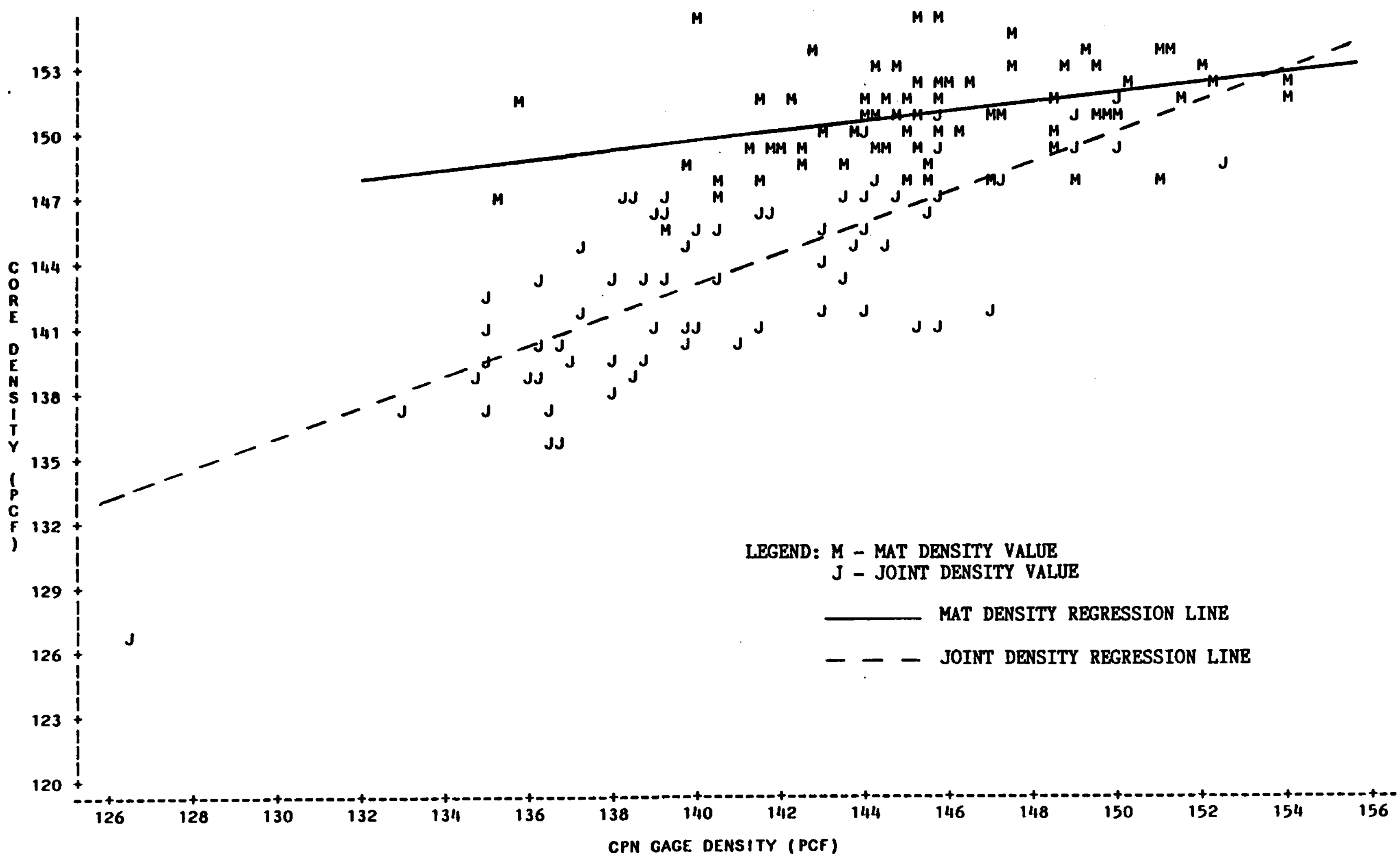

FIGURE 4.24. PLOT OF JOINT AND MAT DENSITY REGRESSION LINES FOR CORE DENSITY VERSUS CPN GAGE DENSITY FOR THE ROCHESTER PROJECT

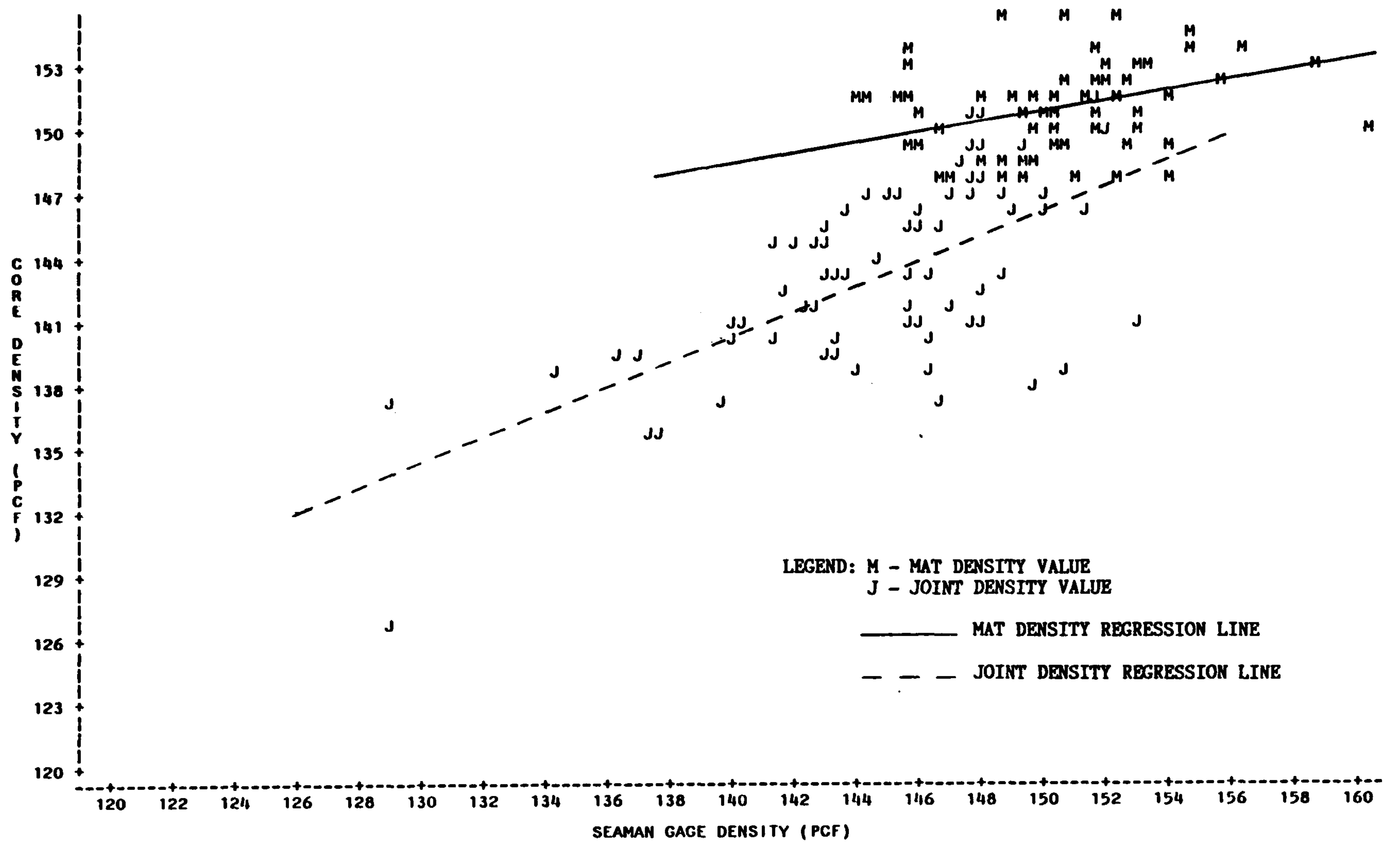

FIGURE 4.25. PLOT OF JOINT AND MAT DENSITY REGRESSION LINES FOR CORE DENSITY VERSUS SEAMAN GAGE DENSITY FOR THE ROCHESTER PROJECT

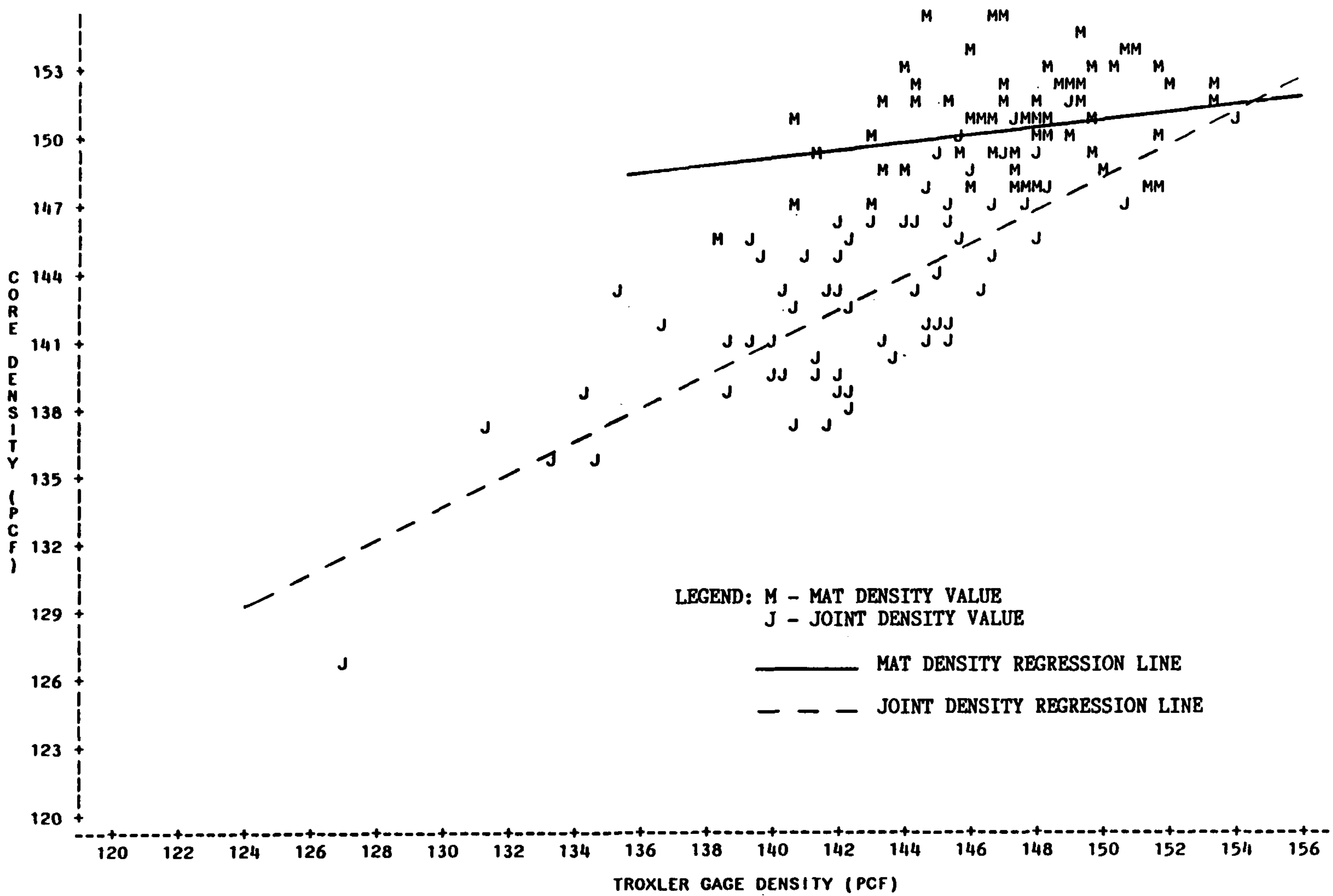

FIGURE 4.26. PLOT OF JOINT AND MAT DENSITY REGRESSION LINES FOR CORE DENSITY VERSUS TROXLER GAGE DENSITY FOR THE ROCHESTER PROJECT

CHAPTER V

RESULTS OF PERCENT COMPACTION ANALYSIS

The previous chapter presents an analysis of the density results for the projects studied. The acceptance procedures employed by the FAA specify that the field density be determined as a percentage of the laboratory density obtained from the Marshall tests. This value is referred to as the percent compaction. If the same percent compaction approach is to be maintained it is necessary to also consider the density values for the projects studied from the standpoint of their percent compaction values.

Both projects studied had price adjustment provisions for mat density based upon the estimated percentage within limits (PWL) value for the lot. An estimated PWL value of 90 or greater was required for 100 percent payment, and the lower acceptance limit was 96.7 percent of the laboratory Marshall density. As noted in Chapter IV, the Morristown project also had a price adjustment provision for joint density that required 90 or greater PWL for 100 percent payment, and the lower acceptance limit was 94.3 percent of the laboratory Marshall density.

This chapter presents the results of an analysis of the percent compaction values for the projects studied. The analyses considered include scatter plots, correlation coefficient determination, hypothesis testing, and regression analysis.

Scatter Plots

Scatter plots were developed to investigate trends and correlations between 1) the mat and joint percent compaction results and 2) the percent compaction results for each gage and the core results. Plots of mat and joint percent compaction results for each project are presented in Figures 5.1 - 5.6. Figures 5.1 - 5.3 present the results for the Morristown project, while the Rochester results appear in Figures 5.4 - 5.6. A listing of all the percent compaction results appears in Appendix B.

Figures 5.1 - 5.6 can be compared with Figures 4.21 - 4.26 that present similar plots for the density values in pounds per cubic foot. The plots show generally similar trends. In both the density and percent compaction plots, the joint density results are generally lower and tend to be more scattered than the mat density values.

Using percent compaction introduces another component of variability that is not present in the density plots. The percent compaction value is the result of dividing the field density by the Marshall laboratory density. Since both the field and laboratory density tests have some inherent variabiltiy, the percent compaction results are likely to be more variable than the case when only the field density is considered. The differences between the mat and joint

results for percent compaction, and between the gage and core percent compaction results, are quantified and discussed in the next section.

Hypothesis Testing

Percent compaction values were determined for the acceptance test results for each of the projects studied. For Morristown, 40 mat and 40 joint percent compaction values were determined for the core densities and for the readings for each of the 3 gages. For Rochester, a total of 144, 72 mat and 72 joint, percent compaction values were determined for each of the 4 sources (i.e., cores and the 3 gages).

The TTEST procedure in SAS was used to perform hypothesis tests on the data. The 2 data sets tested by the procedure were the mat and joint percent compaction results. The analysis was conducted individually for each of the projects. Tables 5.1 and 5.2 present the hypothesis test results for the data from Morristown and Rochester, respectively. These tables are analogous to Tables 4.1 and 4.2 that present results from a similar analysis on the field density values.

For all 4 sources for each project the mat values are statistically significantly larger than the joint values at the .0001 significance level. This confirms the visual observations of Figures 5.1 - 5.6, and is also consitent with the field density results. This is to be expected since the mat and joint percent compaction are both calculated from the same laboratory density, and the mat field density values are shown to be higher than the field joint density values in Tables 4.1 and 4.2.

The joint standard deviations are larger than the mat standard deviations for each of the 4 sources for both of the projects. However, the differences are not statistically significant (.05 level) for the core, CPN, and Troxler values at Morristown, or for the CPN and Seaman values at Rochester. The general trend and the visual observation of the scatter plots in Figures 5.1 - 5.6 would tend to lead to the conclusion that the joint results are more variable than the mat values.

In both Tables 5.1 and 5.2 the gage results are lower than the core results. In each table the relative magnitudes of the mean mat results are the same, with the means increasing from the CPN mean, the smallest, to the Troxler, Seaman and core mean, the largest. The UNIVARIATE procedure in SAS was used to test whether these different mean values were statistically significant. Each reading for each of the 3 gages was subtracted from the corresponding core value. The UNIVARIATE procedure was then used to test whether the mean of these differences was different from zero. If the mean of the differences for a particular gage is statistically different from zero, then that gage's results are statistically significantly different from the core results. The UNIVARIATE procedure was used to compare the mean values for each of the 3 gages with the core results for each project individually, and for the mat and joint results. The results from this procedure are presented in Tables 5.3 and 5.4 for Morristown and Rochester, respectively.

For Morristown, all 3 gages for both mat and joint percent compaction are significantly different (.003 level) from the core results. For Rochester, the Seaman mat values (.10 level) and the Troxler joint values (.25 level) are not significantly different from the core results. The results are consistent with the analysis of the density values presented in Tables 4.12 and 4.13, i.e., the gage readings are generally significantly different from the core values.

Correlation Analysis

Since percent compaction values were determined for each of the 3 gages at each of the coring locations, it is possible to correlate the results for each of the individual gages among themselves and also with the core results. Tables 5.5 and 5.6 present the mat percent compaction correlation coefficients for the Morristown and Rochester projects, respectively. The joint percent compaction results are presented in Tables 5.7 and 5.8.

There is no consistency among the mat percent compaction correlation coefficients from one project to the other. For Morristown, the mat coefficients (Table 5.5) are reasonably consistent, varying from 0.73 to 0.88. Each of the gages correlates approximately equally with the core results (.73, .74 and .78 for CPN, Seaman and Troxler, respectively). For Rochester, on the other hand, there is very little consistency among the mat percent compaction correlation coefficients. The coefficients range in value from 0.19 to 0.69. The gages do not correlate as well with the core results at Rochester as at Morristown. The coefficients between the gages and the core values are 0.19, 0.41 and 0.35 for the CPN, Seaman and Troxler gages, respectively.

The joint percent compaction correlation coefficients are presented in Tables 5.7 and 5.8. For Morristown, the gages do not correlate as well with the core values for joint percent compaction as they do for the mat values in Table 5.5. The joint core correlations are consistent however, varying from 0.46 to 0.52. There is a relatively high correlation among the gages in Table 5.7, with values ranging from 0.82 to 0.89. For Rochester, there is a higher correlation between each of the gages and the core joint compaction results than there is among the gages themselves.

It is very difficult to draw conclusions from the results presented in Tables 5.5 through 5.8. In light of the lack of any consistent pattern in the results, it can only be concluded that the nuclear density gages may perform differently with respect to determining percent compaction on different projects. These differences may be due to environmental factors or to differences in the mixes and materials at the different projects.

Regression Analysis

To further investigate the predictive relationship between the gages and the core results, regression analyses were conducted on the

CHAPTER VI

CONCLUSIONS AND ACCEPTANCE RECOMMENDATIONS

This report has summarized a research project to investigate the use of nuclear density gages for acceptance purposes and to recommend procedures for incorporating joint density in the FAA P-401 specification. The previous chapters have presented the procedures employed in the collection and analysis of field data from 2 bituminous paving projects. These were the only 2 acceptable projects that could be identified by the FAA Eastern Region for the collection of field data during the 1984 construction season. The findings and conclusions of the data analysis are summarized in the following section. Some recommendations on the use of nuclear density gages and on acceptance procedures for joint density are then presented.

Research Findings

The major findings of the research effort described in the preceding chapters are as follow:

1. Joint density and percent compaction values were consistently and statistically significantly lower than mat density and percent compaction values for both projects studied. This was true for both the nuclear gage and core results. This confirms the previous limited data that were available.

2. Joint density values were statistically significantly more variable than the mat density values for the nuclear gages on both projects. The joint core results were significantly more variable than the mat core results for the Rochester data but not for the Morristown data. The percent compaction joint results were not as consistently more variable than the mat results, however the same general trend was still apparent.

3. The level of correlation between the mat and joint density results varied from project to project. The level of correlation among the nuclear gages also was not constant.

4. Statistically significant differences were found in the nuclear gage results for both projects studied. Both the means and variances were found to differ significantly among the gages on both projects, but the differences in the means were more pronounced.

5. In all cases for both projects the gage results had statistically significantly lower mat mean density values than the core mean value. The same general trend was also found in the joint results with the exception of the Seaman gage at Rochester that was significantly larger than the core joint values.

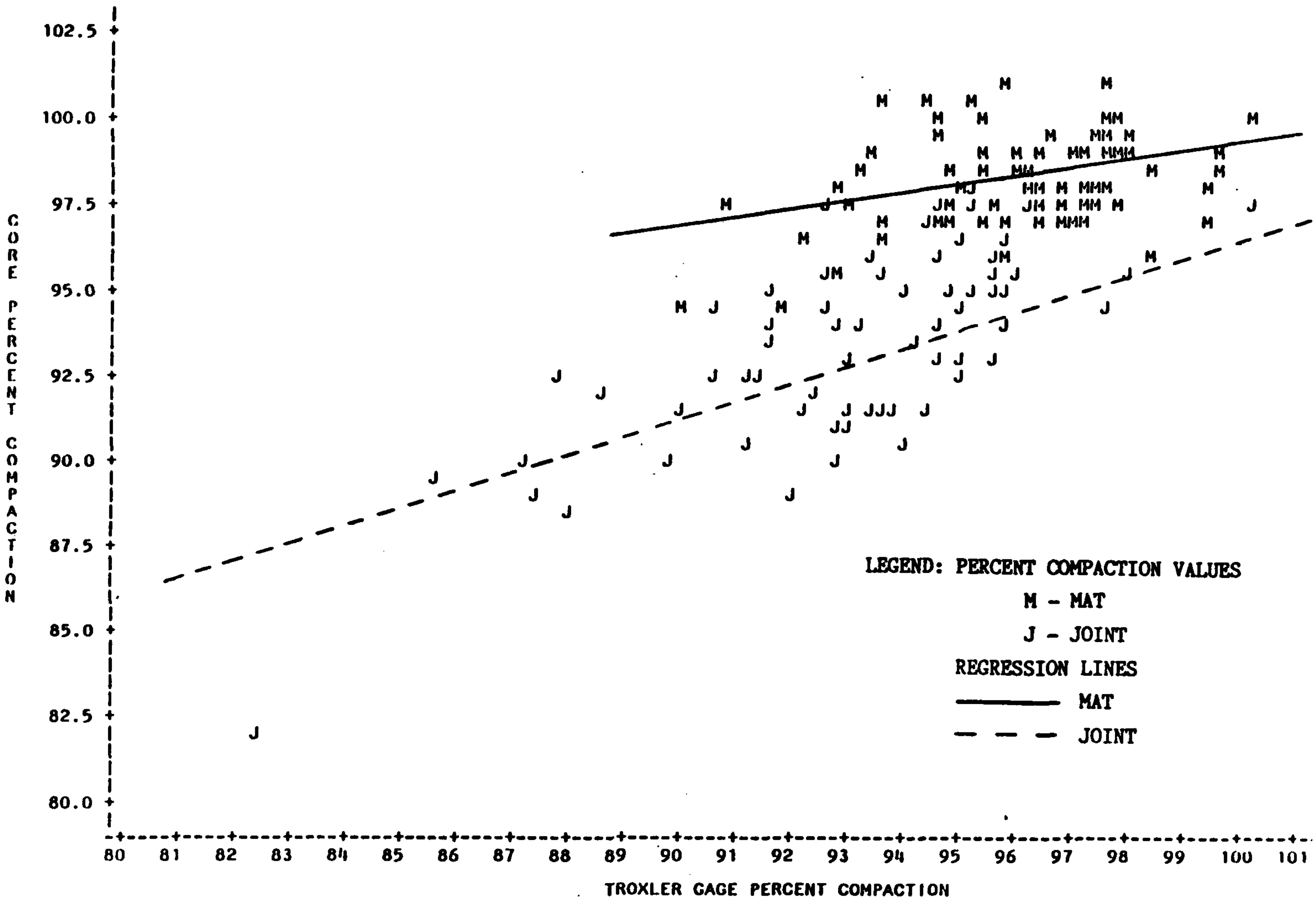

FIGURE 5.6. PLOT OF JOINT AND MAT PERCENT COMPACTION DATA AND REGRESSION LINES FOR CORE VERSUS TROXLER GAGE VALUES FOR THE ROCHESTER PROJECT

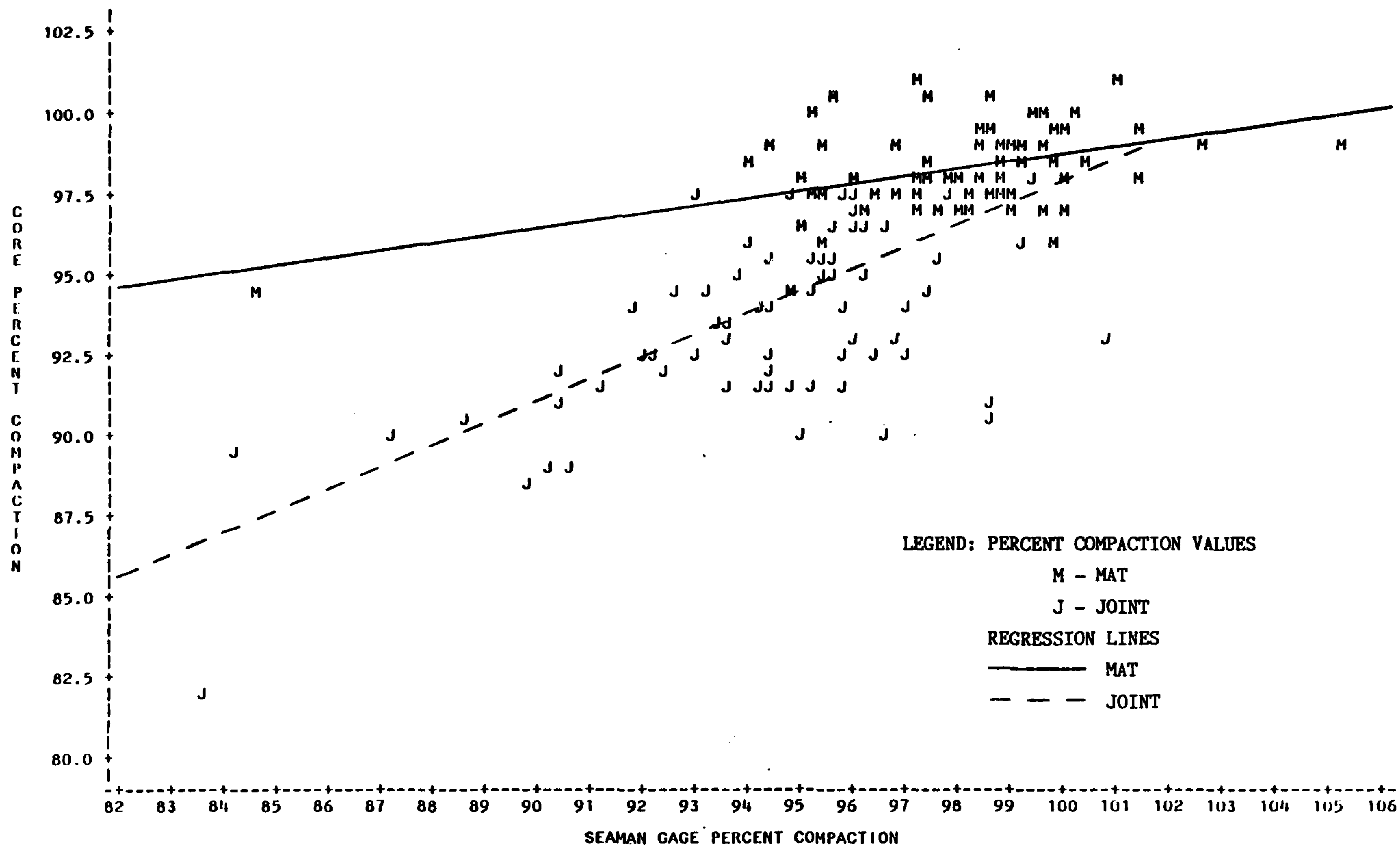

FIGURE 5.5. PLOT OF JOINT AND MAT PERCENT COMPACTION DATA AND REGRESSION LINES FOR CORE VERSUS SEAMAN GAGE VALUES FOR THE ROCHESTER PROJECT

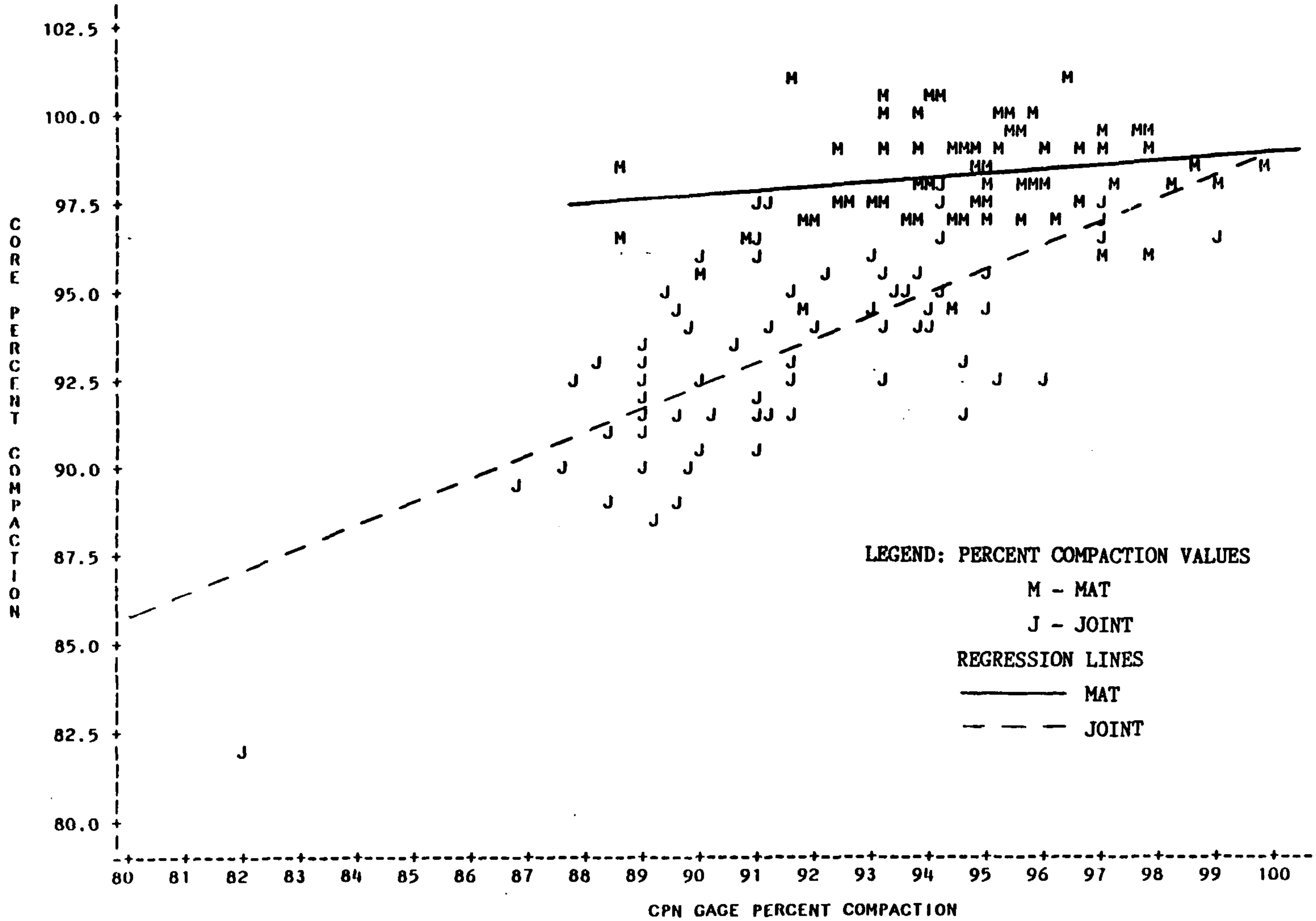

FIGURE 5.4. PLOT OF JOINT AND MAT PERCENT COMPACTION DATA AND REGRESSION LINES FOR CORE VERSUS CPN GAGE VALUES FOR THE ROCHESTER PROJECT

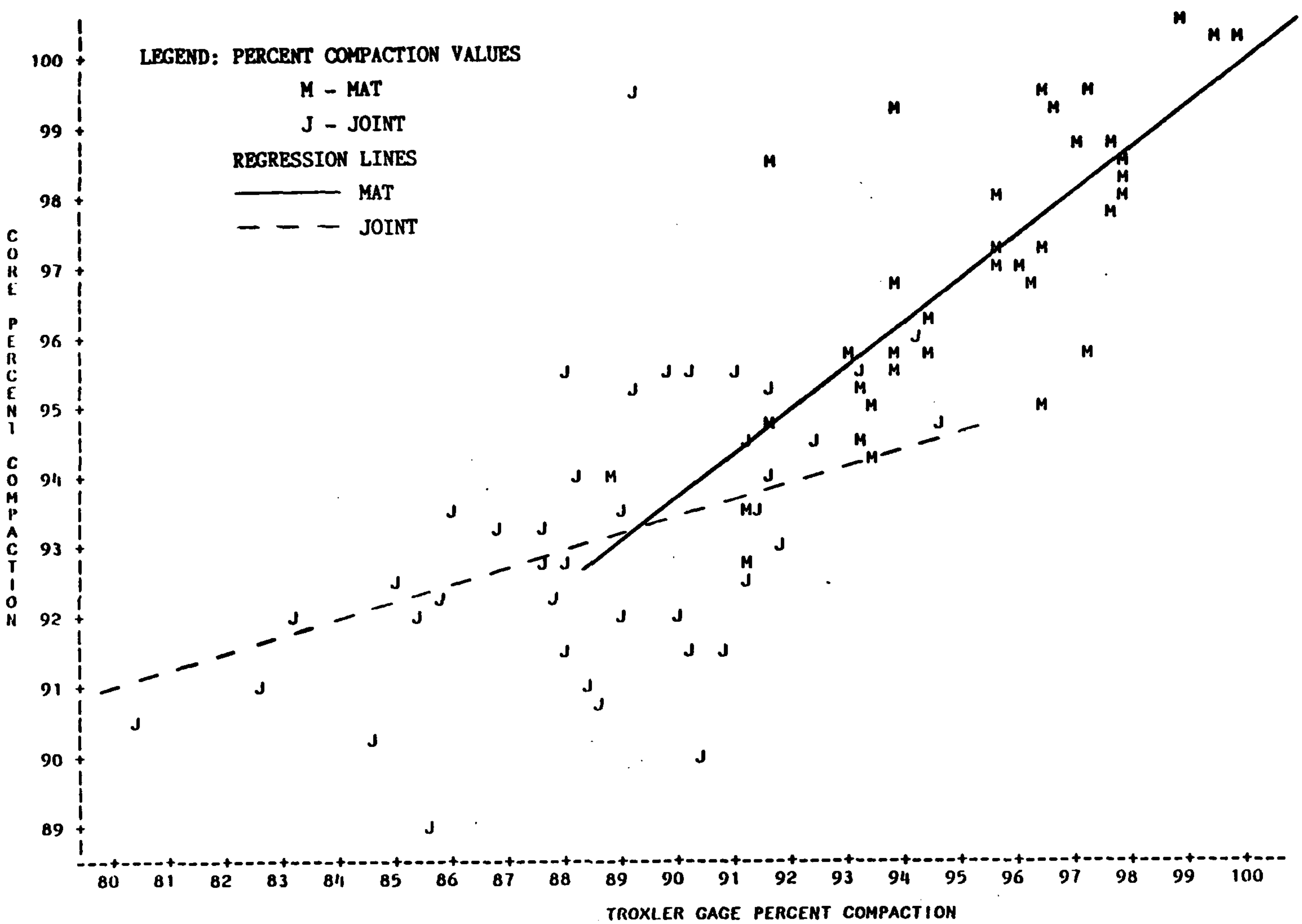

FIGURE 5.3. PLOT OF JOINT AND MAT PERCENT COMPACTION DATA AND REGRESSION LINES FOR CORE VERSUS TROXLER GAGE VALUES FOR THE MORRISTOWN PROJECT

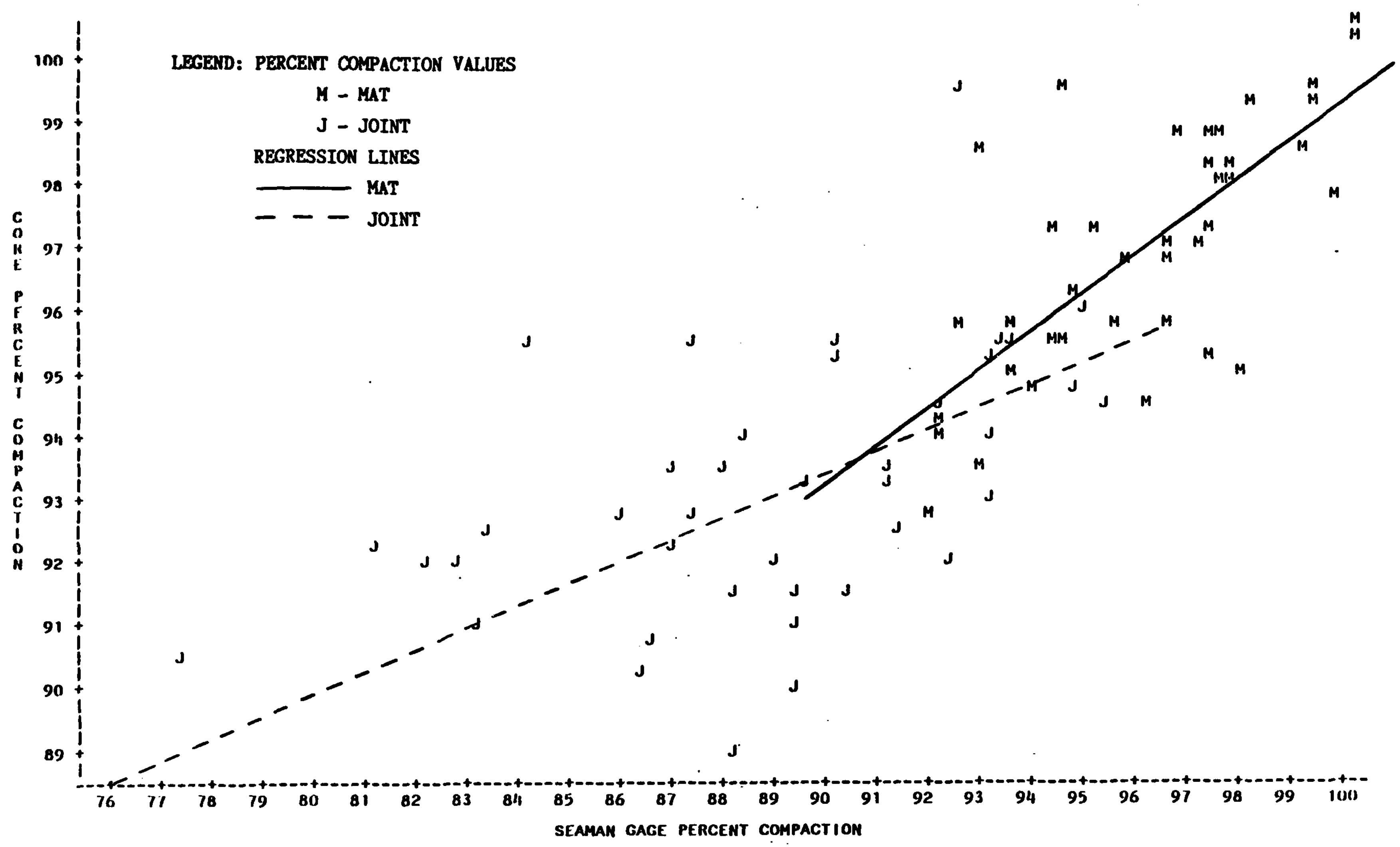

FIGURE 5.2. PLOT OF JOINT AND MAT PERCENT COMPACTION DATA AND REGRESSION LINES FOR CORE VERSUS SEAMAN GAGE VALUES FOR THE MORRISTOWN PROJECT

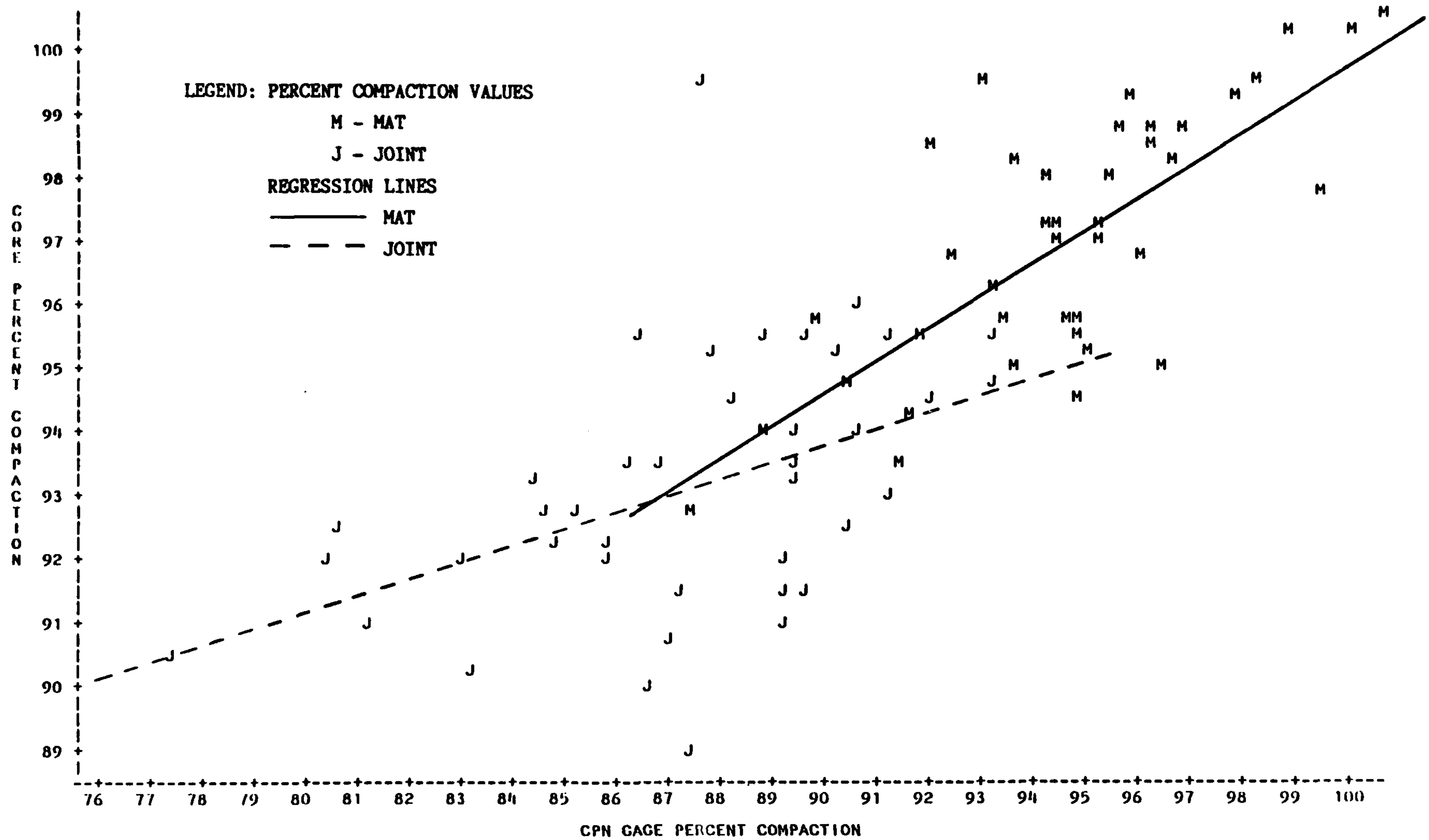

FIGURE 5.1. PLOT OF JOINT AND MAT PERCENT COMPACTION DATA AND REGRESSION LINES FOR CORE VERSUS CPN GAGE VALUES FOR THE MORRISTOWN PROJECT

TABLE 5.11. RESULTS OF REGRESSION ANALYSIS ON GAGE AND CORE JOINT PERCENT COMPACTION RESULTS FOR THE MORRISTOWN PROJECT (40 OBSERVATIONS).

GAGE	SLOPE	t-STATISTIC (PROB > |t|)*	INTERCEPT	t-STATISTIC (PROB > |t|)*	R-SQUARE
CPN	0.269	3.2 (.0026)	69.67	9.6 (.0001)	0.194
TROXLER	0.346	3.8 (.0006)	62.43	7.6 (.0001)	0.252
SEAMAN	0.251	3.6 (.0001)	70.88	11.34 (.0001)	0.231

* - probability of obtaining a t value as large as the one shown if the true slope or intercept is actually zero

TABLE 5.10. RESULTS OF REGRESSION ANALYSIS ON GAGE AND CORE JOINT PERCENT COMPACTION RESULTS FOR THE ROCHESTER PROJECT (72 OBSERVATIONS).

GAGE	SLOPE	t-STATISTIC (PROB > |t|)*	INTERCEPT	t-STATISTIC (PROB > |t|)*	R-SQUARE
CPN	0.653	7.9 (.0001)	33.61	4.4 (.0001)	0.464
TROXLER	0.690	8.8 (.0002)	29.15	4.0 (.0001)	0.521
SEAMAN	0.526	6.0 (.0003)	43.84	5.3 (.0001)	0.329

* - probability of obtaining a t value as large as the one shown if the true slope or intercept is actually zero

TABLE 5.9. RESULTS OF REGRESSION ANALYSIS ON GAGE AND CORE MAT PERCENT COMPACTION RESULTS FOR THE MORRISTOWN PROJECT (40 OBSERVATIONS).

GAGE	SLOPE	t-STATISTIC (PROB > |t|)*	INTERCEPT	t-STATISTIC (PROB > |t|)*	R-SQUARE
CPN	0.510	6.6 (.0001)	48.79	6.7 (.0001)	0.523
TROXLER	0.622	7.6 (.0001)	37.77	4.9 (.0001)	0.594
SEAMAN	0.612	6.8 (.0001)	38.11	4.4 (.0001)	0.538

* - probability of obtaining a t value as large as the one shown if the true slope or intercept is actually zero

TABLE 5.10. RESULTS OF REGRESSION ANALYSIS ON GAGE AND CORE MAT PERCENT COMPACTION RESULTS FOR THE ROCHESTER PROJECT (72 OBSERVATIONS).

GAGE	SLOPE	t-STATISTIC (PROB > |t|)*	INTERCEPT	t-STATISTIC (PROB > |t|)*	R-SQUARE
CPN	0.117	1.6 (.1035)	87.05	12.9 (.0001)	0.024
TROXLER	0.238	3.1 (.0024)	75.36	10.4 (.0001)	0.112
SEAMAN	0.222	3.8 (.0003)	76.51	13.3 (.0001)	0.158

* - probability of obtaining a t value as large as the one shown if the true slope or intercept is actually zero

TABLE 5.7. CORRELATION COEFFICIENTS FOR JOINT PERCENT COMPACTION ON THE MORRISTOWN PROJECT (40 OBSERVATIONS)

	CORE	CPN	SEAMAN	TROXLER
CORE	---	.46	.50	.52
CPN	.46	---	.80	.89
SEAMAN	.50	.80	---	.82
TROXLER	.52	.89	.82	---

NOTE - the probability that any individual coefficient in the table would be obtained if the true correlation is zero is smaller than .003

TABLE 5.8. CORRELATION COEFFICIENTS FOR JOINT PERCENT COMPACTION ON THE ROCHESTER PROJECT (72 OBSERVATIONS)

	CORE	CPN	SEAMAN	TROXLER
CORE	---	.69	.58	.73
CPN	.69	---	.50	.70
SEAMAN	.58	.50	---	.67
TROXLER	.73	.70	.67	---

NOTE - the probability that any individual coefficient in the table would be obtained if the true correlation is zero is .0001

TABLE 5.5. CORRELATION COEFFICIENTS FOR MAT PERCENT COMPACTION ON THE MORRISTOWN PROJECT (40 OBSERVATIONS)

	CORE	CPN	SEAMAN	TROXLER
CORE	---	.73	.74	.78
CPN	.73	---	.88	.83
SEAMAN	.74	.88	---	.80
TROXLER	.78	.83	.80	---

NOTE - the probability that any individual coefficient in the table would be obtained if the true correlation is zero is .0001

TABLE 5.6. CORRELATION COEFFICIENTS FOR MAT PERCENT COMPACTION ON THE ROCHESTER PROJECT (72 OBSERVATIONS)

	CORE	CPN	SEAMAN	TROXLER
CORE	---	.19 (.1035)*	.41 (.0003)	.35 (.0024)
CPN	.19 (.1035)	---	.44 (.0001)	.48 (.0001)
SEAMAN	.41 (.0003)	.44 (.0001)	---	.69 (.0001)
TROXLER	.35 (.0024)	.48 (.0001)	.69 (.0001)	---

* - the probability that the coefficient in the table would be obtained if the true correlation is zero

TABLE 5.3. RESULTS OF HYPOTHESIS TESTS ON THE DIFFERENCE BETWEEN NUCLEAR GAGE RESULTS AND CORE RESULTS FOR PERCENT COMPACTION FOR THE MORRISTOWN PROJECT (40 OBSERVATIONS).

GAGE	TYPE	MEAN	STD DEV	t-STATISTIC	PROB > |t|*
CPN	M	-2.49	1.96	-8.02	.0001
	J	-5.85	3.19	-11.59	.0001
SEAMAN	M	-0.83	1.64	-3.18	.0029
	J	-4.31	3.58	-7.61	.0001
TROXLER	M	-1.80	1.58	-7.22	.0001
	J	-4.46	2.70	-10.46	.0001

* - probability of obtaining a t value as large as the one shown if the means are actually equal

TABLE 5.4. RESULTS OF HYPOTHESIS TESTS ON THE DIFFERENCE BETWEEN NUCLEAR GAGE RESULTS AND CORE RESULTS FOR PERCENT COMPACTION FOR THE ROCHESTER PROJECT (72 OBSERVATIONS).

GAGE	TYPE	MEAN	STD DEV	t-STATISTIC	PROB > |t|*
CPN	M	-3.27	2.46	-11.27	.0001
	J	-1.79	2.24	-6.77	.0001
SEAMAN	M	-0.46	2.39	-1.63	.107
	J	0.84	2.67	-2.67	.009
TROXLER	M	-2.18	2.05	-9.03	.0001
	J	-0.28	2.10	-1.15	.253

* - probability of obtaining a t value as large as the one shown if the means are actually equal

TABLE 5.1. RESULTS OF HYPOTHESIS TESTS ON MAT AND JOINT PERCENT COMPACTION DATA FOR THE MORRISTOWN PROJECT

SOURCE	NO.	MAT MEAN (STD DEV)	JOINT MEAN (STD DEV)	F-STATISTIC (PROB > F)*	t-STATISTIC (PROB > |t|)#
CORE	40	97.0 (2.0)	93.2 (2.1)	1.07 (.841)	-8.51 (.0001)
CPN	40	94.5 (2.9)	87.3 (3.6)	1.54 (.182)	-9.99 (.0001)
TROXLER	40	95.2 (2.5)	88.7 (3.1)	1.55 (.177)	-10.34 (.0001)
SEAMAN	40	96.2 (2.4)	88.8 (4.1)	2.90 (.001)	-9.71 (.0001)

* - probability of obtaining an F value as large as the one shown if the variances are actually equal

- probability of obtaining a t value as large as the one shown if the means are actually equal

TABLE 5.2. RESULTS OF HYPOTHESIS TESTS ON MAT AND JOINT PERCENT COMPACTION DATA FOR THE ROCHESTER PROJECT

SOURCE	NO.	MAT MEAN (STD DEV)	JOINT MEAN (STD DEV)	F-STATISTIC (PROB > F)*	t-STATISTIC (PROB > |t|)#
CORE	72	98.2 (1.4)	93.5 (2.8)	3.89 (.0001)	-12.89 (.0001)
CPN	72	94.9 (2.3)	91.7 (2.9)	1.58 (.057)	-7.37 (.0001)
TROXLER	72	96.0 (2.1)	93.2 (2.9)	1.96 (.0004)	-6.56 (.0001)
SEAMAN	72	97.7 (2.6)	94.3 (3.0)	1.38 (.181)	-7.19 (.0001)

* - probability of obtaining an F value as large as the one shown if the variances are actually equal

- probability of obtaining a t value as large as the one shown if the means are actually equal

percent compaction data. Linear regression analyses were conducted on the data from each project and for each gage individually. The analyses were conducted to determine how well each gage predicted the core percent compaction results. The results of the regression analyses are presented in Tables 5.9 - 5.12. Tables 5.9 and 5.10 present the mat percent compaction results for the Morristown and Rochseter projects, respectively. The joint percent compaction results appear in Tables 5.11 and 5.12.

The tables present the regression equations using each of the gage percent compaction results as the independent variable and the core percent compaction results as the dependent variable. The slopes and intercepts, along with the t-statistic for testing whether the slope and intercept values are different from zero, are presented with the R-square values for each regression equation. To illustrate the relationships of the regression equations to the data, Figures 5.1 - 5.6 present plots of the mat and joint percent compaction values along with the regression lines for each gage for each project.

As in Figures 4.21 - 4.26 for the density results, there is no consistency between the 2 projects with respect to the percent compaction plots in Figures 5.1 - 5.6. For Morristown, the mat regresson lines have steeper slopes than the corresponding joint lines. For Rochester, the mat regression lines have very shallow slopes (the CPN gage slope is not significantly different from zero at the .10 level). The mat R-square values for Rochester are extremely low, indicating that none of the gages did a very good job of predicting the core percent compaction values. The joint R-square values for Morristown are also quite low. From the results presented in Tables 5.9 - 5.12 and the plots in Figures 5.1 - 5.6, it appears that the ability of the gages to predict core percent compaction values will vary from project to project.

6. When using nuclear gages for determining joint density, it was found that orienting the gage perpendicular rather than parallel to the joint provided results that were closer to the joint core density values.

7. Regression analyses indicated that the predictive ability of the nuclear gages with respect to the core results varied from project to project. For Morristown, mat density regression equations yielded R-square values of 0.493, 0.655 and 0.594 for the CPN, Troxler and Seaman gages, respectively. The corresponding R-square values for mat density on the Rochester project were 0.130, 0.081 and 0.120.

8. The mat percent compaction results were significantly larger than the joint percent compaction results for all 3 gages and for cores on both projects.

9. The core percent compaction results were generally statistically significantly larger than the nuclear gage percent compaction results.

10. The correlation between the gage and core mat percent compaction results varied widely between the 2 projects. For Morristown, the correlation coefficients between the core results and the CPN, Seaman and Troxler gages were 0.73, 0.74 and 0.78, respectively. For Rochester the coefficients were 0.19, 0.41 and 0.35. The joint percent comapaction correlations were more consitent than the mat values.

11. As with the density values, the regression analyses to predict core percent compaction from the gage percent compaction values were not consistent for the 2 projects. The R-square values for mat percent compaction at Rochester were very low (0.024 to 0.158). The Morristown R-square values for percent compaction were 0.523, 0.594 and 0.538 for the CPN, Troxler and Seaman gages, respectively. The joint percent compaction R-square values were also quite low for the Morristown project.

Acceptance Plan Recommendations

Recommendations from this research with respect to acceptance procedures can be divided into 2 categories: 1) those dealing with joint density and 2) those dealing with the use of nuclear density gages. Each of these areas is addressed in the following sections.

Joint Density Acceptance Procedures

This research has shown that the joint density values attained on projects are significantly smaller than the mat density values. If joint density is to be considered as an acceptance characteristic and evaluated in the same manner that mat density is evaluated, then appropriate acceptance limits must be established. The current mat density acceptance procedures based on the Percentage of the material Within the acceptance Limits (PWL) can also be employed for joint

density if appropriate acceptance limits are established.

The current FAA procedures allow for full payment for a lot of material if the estimated PWL value for the lot is 90 or greater. If this same philosophy is applied to the joint density acceptance decision, then the lower acceptance limit for joint density can be calculated. Since the 2 projects on which data were colected were selected by the FAA Eastern Region to be indicative of the quality level that can be attained on typical projects, the mean values for the 2 projects can be used to establish the acceptance limits. The joint percent compaction results for Morristown and Rochester are presented in Tables 5.1 and 5.2. For Morristown, the mean and variance for the joint core percent compaction values were 93.2 and 2.1, respectively. For Rochester, the corresponding values were 93.5 and 2.8.

It should be noted that the Morristown project had a price adjustment provision for mat density, while the Rochester project had no density specification requirement. The price adjustment provision at Morristown may be responsible for the smaller standard deviation at Morristown as compared with Rochester. The mean values for the 2 projects are very similar. If the representative values for high quality construction are based on the results of these projects, then it may be assumed that it is reasonable to expect that the higher qualtiy of the values can be obtained in the field. The acceptance limits could then be based on a population mean and standard deviation of 93.5 and 2.1, respectively.

With the mean and standard deviation for the joint population established, a table of the normal distribution can be used to determine the acceptance limit as the value that has 90 percent of the population above it. This value will be 1.282 standard deviations below the population mean (6). For the population in question, the acceptance limit would therefore be $93.5 - (1.282 \times 2.1) = 90.8$.

The above approach for establishing the acceptance limit is based on the assumption that the 2 projects studied are indicative of acceptable construction quality levels. Since the projects were selected by the FAA to be indicative of such quality, the results should yield an appropriate acceptance limit. If it is believed that these projects are not indicative of acceptable quality construction, then the same procedure could be used to establish the acceptance limit based on the population mean and standard deviation that were considered by the FAA to be indicative of an acceptable quality level.

Comments on the Percent Compaction Approach

The FAA has traditionally used the percent compaction based on the laboratory Marshall density for determining the field compaction values. There are several potential disadvantages to this approach that should be noted. As noted in a previous chapter, the percent compaction approach introduces another element of variability into the acceptance process, i.e., the determination of the laboratory density value. The percent compaction value is the result of dividing the field density by

the Marshall laboratory density. Since both the field and laboratory density tests have some inherent variabilty, the percent compaction results have an added element of variability from the laboratory density that is not present when only the field density is considered.

Another potential problem is the fact that there is no direct correlation between the individual laboratory densities and the field density results. This necessitates the use of an average laboratory density against which each of the individual field densities is measured. This averaging process introduces another potential source of variability into the percent compaction results.

A final problem that can be encountered with the use of the percent compaction approach relates to the situation when a cold joint is formed by placing material from the current lot against material from a previously place lot. The problem relates to which of the laboratory densities, i.e., from the new lot being placed or from the old lot already in place, should be used to determine the percent compaction.

For example, if the old lot had an average laboratory density of 150 pounds per cubic foot (pcf) and the new lot has a laboratory density of 155 pcf, what is the percent compaction if the joint core density is 145 pcf? If the new laboratory density is used, then the percent compaction is (145/155) x 100 = 93.5. However, if the laboratory density of the old lot is used, then the percent compaction is (145/150) x 100 = 96.7.

The procedure that was used by the FAA on the projects studied was to use the laboratory density from the new lot as the base against which to measure percent compaction. This was therefore the procedure that was used in developing the percent compaction values presented in Chapter V. It seems reasonable to use the smaller of the 2 laboratory densities to calculate percent compaction in a situation such as the one just presented. Another possibility is to use the average of the 2 laboratory densities in calculating percent compaction.

An approach that avoids the above noted problems with the percent compaction procedures is to base acceptance on the in-place air voids as determined from the specific gravities of the cores and the maximum specific gravity for the cores as measured by ASTM D-2041. This approach eliminates the added variability component introduced by the laboratory density and avoids altogether the problem of which laboratory density to use when 2 lots form a construction joint. The in-place air voids approach has the disadvantage of not having the large amounts of historical data that the FAA already has available for the percent compaction approach. The in-place air voids approach is recommended as a viable alternative that eliminates the problems associated with applying the percent compaction approach to joint density acceptance decisions.

Use of Nuclear Gages for Acceptance

The second major area to consider from the research with respect to acceptance procedures is whether nuclear gages should be used in acceptance decisions instead of or as an alternative to cores. Before considereing this topic, it should be noted that any conclusions and discussions presented in this report can apply only to the gages used in this study. They can not necessarily be applied to a particular manufacturer's gages in general since there is bound to be some degree of variability among the gages produced even by a single gage manufacturer.

The results of this research have shown that the readings of the 3 gages can be statistically significantly different from one another and also from the core results. Furthermore, it was found that there is no consistency with respect to how the gages will perform with respect to one another from one project to the next. If the intent of using nuclear gages is to provide an estimate for, or to correlate with, the core results, then the findings of this research do not support the use of nuclear gages for acceptance decisions. The use of nuclear gages in lieu of coring, but with the same acceptance limits that were developed based on core results, is not appropriate.

The use of nuclear gages, however, has some distinct advantages over the use of cores. These advantages are related to the number of tests that can be conducted non-destructively with the nuclear gages in a short period of time. This allows for a large number of acceptance tests at random locations that can more thoroughly sample the total area of the paving lot. The nuclear gages have the advantage of allowing the acceptability of the lot to be determined without having to wait for the cores to be transported to the laboratory and tested. It is this continuous feedback aspect of nuclear gages that has led to their popularity as quality control devices by paving contractors.

Since this research found that the nuclear gages did not consistently correlate with the core results from project to project and for mat and joint densities, it is important that a test strip be used if nuclear gages are to be considered for acceptance. The particular gage that will be used on the project can be used on the test strip to determine the maximum density that is attained on the test strip. This approach of using the same gage that will be used on the project on a test strip that is constructed with the same mix and materials that will be used on the project should eliminate some of the variability that was found among the projects studied in the current research.

The results of this research indicate that nuclear gages probably should not simply be substituted into the current acceptance plan in place of cores because the current acceptance limits and procedures were developed from historical core data. This should not rule out the development of acceptance procedures specifically for nuclear gages to take advantage of the large sample sizes and rapid results that are possible with nuclear gages.

Recommended Acceptance Plan

Since this research was based on gathering data from acceptance test results so as to not interfere with the construction operations at the project sites, it was not possible to gather data on the use of in-place air voids or the use of nuclear gages with test strips for acceptance decisions. Also, the only payment schedule that has been employed for joint density considerations is the one used by the FAA Eastern Region on the Morristown project. It is based on PWL and provides a price adjustment per lineal foot of joint for PWL values below 90. The schedule provides for a linear price reduction that calls for a price adjustment of $1.00 per foot for 65 PWL and below that decreases linearly to no price adjustment for 90 PWL and above. Based on the data that were collected and analyzed as a part of this research effort, the following acceptance procedures are recommended.

1. Use the random sampling procedures in the Eastern Region Laboratory Procedures Manual to determine 4 locations along the joint from which to drill cores.

2. Determine the field density for each of the cores.

3. Determine the average laboratory density for the Marshall tests conducted on the lot.

4. Determine the percent compaction for each field core by dividing its field density by the average laboratory density for the lot. For joints between lots, the lower average laboratory density for the 2 lots should be used in the percent compaction calculation.

5. Determine the estimated PWL value using the Quality Index procedures in the FAA Eastern Region P-401 specification.

6. Using the payment schedule for joint density in the FAA Eastern Region P-401 specification and the estimated PWL value, determine the payment reduction for joint density. This reduction would be applied in addition to any mat density price reduction.

As noted previously, these recommendations are based on the assumption that the projects that were supplied by the FAA Eastern Region for data collection are indicative of the level of quality that can be attained under field conditions. If the level of quality on these projects is inferior, then the limits that are based on the results may be too lenient. If the quality on these projects is unusually high, then the acceptance limits based on the results may be difficult to meet.

Even though it was not possible to gather such data on this research project, serious consideration should be given to the use of in-place air voids to eliminate some of the cited problems in using percent compaction for both mat and joint density acceptance decisions. The use of nuclear density gages in conjunction with a test strip should also be considered as an alternative to the use of cores for acceptance decisions. If nuclear gages are to be used for joint density

determination, the gage should be oriented perpendicular to the joint when the density reading is obtained. Nuclear density gages should not simply be used in place of cores in the current FAA acceptance procedures since the current procedures, including the acceptance limits, were developed from historical core data.

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APPENDIX A

DENSITY RESULTS

The acceptance test location density results for the Morristown project are listed below. The column labeled TYP identifies whether the values are for mat (M) or joint (J) readings. The CPNBS, TROXLR, SEAMAN and CORE columns are for the CPN gage in the BS mode, the Troxler gage, the Seaman gage and the core results, respectively.

Acceptance Test Location Density Results - Morristown

LOT	TYP	CPNBS	TROXLR	SEAMAN	CORE
1	J	132.0	134.1	135.6	143.3
1	J	130.6	133.8	130.8	140.8
1	J	136.3	132.7	132.8	141.5
1	J	135.9	137.1	137.5	139.2
1	M	144.7	146.7	145.5	148.4
1	M	143.6	145.9	146.5	148.6
1	M	142.0	143.8	143.1	146.4
1	M	150.4	150.2	151.9	150.8
2	J	136.3	141.1	142.6	146.3
2	J	137.8	139.4	139.7	141.6
2	J	131.6	136.1	133.0	143.5
2	J	134.4	137.1	133.8	140.5
2	M	155.5	152.9	156.3	155.3
2	M	151.1	149.3	153.8	153.7
2	M	153.6	150.8	154.4	151.4
2	M	142.0	143.9	145.9	147.6
3	J	134.2	136.8	135.8	148.2
3	J	120.1	124.8	120.2	140.6
3	J	128.9	132.5	127.7	142.9
3	J	144.9	144.6	145.1	148.2
3	M	144.9	146.7	147.3	149.7
3	M	147.1	146.7	145.4	148.7
3	M	142.2	145.0	143.3	146.6
3	M	150.1	151.9	151.8	152.8
4	J	139.0	136.1	140.2	141.3
4	J	141.6	143.1	146.8	146.1
4	J	132.2	134.5	137.3	143.5
4	J	141.6	140.4	142.1	144.8
4	M	153.1	153.1	155.7	151.0
4	M	143.8	145.6	149.4	150.8
4	M	150.7	148.1	152.7	150.4
4	M	152.5	152.8	153.4	153.8
5	J	137.5	143.1	140.9	144.1
5	J	136.5	142.5	141.0	143.5
5	J	144.9	145.8	150.4	149.2
5	J	140.6	138.6	139.1	144.5
5	M	148.9	151.4	153.2	153.1
5	M	149.5	153.3	151.3	150.9
5	M	147.7	147.3	147.6	149.9
5	M	150.1	150.7	152.4	152.1
6	J	145.2	143.6	149.1	151.9
6	J	136.3	141.5	141.7	146.3
6	J	145.2	146.0	148.2	148.0
6	J	139.3	142.0	147.4	158.4
6	M	148.6	149.3	153.8	152.5
6	M	145.8	149.2	152.4	153.9
6	M	157.2	158.2	161.5	159.6
6	M	151.0	149.3	150.5	151.8
7	J	147.5	150.2	150.5	150.6
7	J	141.9	145.1	144.9	148.7
7	J	143.0	145.5	147.9	151.1
7	J	136.8	136.0	139.3	148.4

LOT	TYP	CPNBS	TROXLR	SEAMAN	CORE
7	M	151.0	153.0	149.8	154.6
7	M	152.8	155.2	157.4	156.7
7	M	140.9	140.8	146.4	149.5
7	M	145.2	144.7	147.5	148.5
8	J	133.0	134.5	127.4	144.9
8	J	140.3	137.4	143.1	146.5
8	J	140.8	143.7	146.2	147.8
8	J	127.5	129.7	130.5	142.9
8	M	150.3	153.4	154.2	155.8
8	M	149.7	150.1	153.5	153.9
8	M	147.4	150.0	152.7	152.7
8	M	146.8	153.4	153.1	154.2
9	J	138.8	140.3	141.0	149.4
9	J	133.9	137.1	135.9	144.2
9	J	132.0	135.6	140.1	145.9
9	J	141.4	147.1	148.5	150.1
9	M	148.5	151.6	152.4	154.3
9	M	153.3	151.8	155.3	155.6
9	M	136.6	142.6	143.6	144.9
9	M	140.3	145.4	144.8	149.6
10	J	138.0	140.2	143.7	147.3
10	J	123.8	128.0	127.3	141.8
10	J	124.2	130.9	128.4	142.3
10	J	130.3	134.8	134.6	142.8
10	M	146.1	143.3	149.8	153.4
10	M	143.1	148.5	145.6	149.9
10	M	141.6	140.9	143.1	151.7
10	M	144.9	150.5	150.2	151.1

The random location density results for the Morristown project are listed below. The column labeled TYP identifies whether the values are for mat (M) or joint (J) readings. The CPNBS, TROXLR and SEAMAN columns are for the CPN gage in the BS mode, the Troxler gage and the Seaman gage results, respectively.

<u>Random Location Density Results - Morristown</u>

LOT	TYP	CPNBS	TROXLR	SEAMAN
1	J	137.3	142.4	138.2
1	J	133.9	130.6	137.2
1	J	137.8	139.7	137.1
1	J	137.3	137.6	133.0
1	J	133.4	135.2	133.4
1	J	132.5	132.2	132.5
1	J	136.8	136.2	135.0
1	J	138.8	140.3	141.0
1	J	130.2	130.3	126.2
1	J	127.5	127.2	122.6
1	J	128.8	128.9	127.7
1	J	132.5	133.3	133.6
1	J	133.0	134.0	131.0
1	J	135.8	135.3	137.0
1	J	133.4	135.6	135.6
1	J	133.9	133.2	131.3
1	J	135.3	135.0	131.9
1	J	132.5	132.0	132.9

LOT	TYP	CPNBS	TROXLR	SEAMAN
1	J	131.5	132.9	131.6
1	J	126.4	123.7	131.5
1	M	148.6	149.4	148.0
1	M	147.5	146.2	148.5
1	M	144.1	148.8	146.4
1	M	146.9	146.8	146.0
1	M	148.0	146.8	148.6
1	M	144.6	143.6	146.6
1	M	141.9	142.3	141.0
1	M	146.9	146.3	148.0
1	M	145.2	142.7	142.5
1	M	143.6	145.2	143.7
1	M	149.8	148.8	148.9
1	M	146.3	.	144.9
1	M	142.5	141.7	142.0
1	M	144.1	144.2	141.5
1	M	146.3	145.5	144.3
1	M	146.3	145.2	144.3
1	M	142.5	142.4	142.0
1	M	144.1	142.4	142.2
1	M	141.4	142.1	139.8
1	M	144.1	144.0	142.7
2	J	131.1	133.9	130.0
2	J	136.3	137.5	135.4
2	J	135.4	134.9	136.5
2	J	144.2	141.5	144.3
2	J	136.8	140.5	137.0
2	J	134.9	137.1	137.7
2	J	132.5	135.3	132.8
2	J	133.1	134.8	131.9
2	J	147.1	136.8	134.3
2	J	136.5	136.8	134.4
2	M	143.1	141.1	140.2
2	M	150.5	148.0	148.4
2	M	143.6	141.6	143.3
2	M	144.2	144.7	146.2
2	M	147.0	145.2	147.7
2	M	145.3	146.1	144.9
2	M	145.3	146.5	145.7
2	M	154.3	150.9	153.9
2	M	148.9	151.2	149.9
2	M	142.2	144.8	143.8
3	J	134.1	137.6	134.4
3	J	128.5	128.4	128.2
3	J	126.3	127.9	125.2
3	J	128.1	130.6	127.8
3	J	138.0	139.1	140.7
3	J	136.5	137.6	135.7
3	J	133.6	133.3	132.2
3	J	137.5	136.7	136.1
3	J	136.0	136.3	134.1
3	J	134.1	135.3	135.0

LOT	TYP	CPNBS	TROXLR	SEAMAN
3	J	131.7	134.5	134.9
3	J	134.6	133.7	134.0
3	J	138.0	138.6	136.4
3	J	141.6	141.9	141.4
3	J	133.1	136.2	133.4
3	M	147.3	147.4	150.2
3	M	143.2	145.6	146.5
3	M	145.4	143.3	146.8
3	M	142.7	144.1	146.2
3	M	148.3	148.5	150.9
3	M	146.6	145.7	148.6
3	M	141.1	142.7	141.1
3	M	147.7	146.6	145.7
3	M	139.0	139.5	138.7
3	M	148.3	150.5	155.0
3	M	148.9	147.9	151.5
3	M	144.3	147.1	146.5
3	M	144.3	145.4	142.0
3	M	147.7	148.9	149.0
3	M	150.1	149.4	150.4
4	J	136.8	141.9	135.6
4	J	137.8	141.7	142.0
4	J	141.4	141.3	141.1
4	J	146.9	147.7	151.6
4	J	133.9	139.5	139.1
4	J	142.5	145.2	142.8
4	J	145.8	146.6	146.2
4	J	137.8	140.4	137.5
4	J	142.5	144.2	142.5
4	J	141.4	141.6	140.6
4	J	146.3	146.6	151.0
4	J	144.6	147.0	150.7
4	J	135.8	137.5	139.7
4	J	135.8	137.5	139.7
4	J	141.4	139.9	140.7
4	M	146.3	149.7	147.5
4	M	151.6	154.3	156.2
4	M	149.8	151.5	151.1
4	M	145.8	147.9	144.6
4	M	148.0	150.7	151.9
4	M	149.2	151.2	153.2
4	M	142.5	146.3	148.3
4	M	142.5	146.9	146.9
4	M	149.2	150.7	149.1
4	M	143.0	146.4	143.3
4	M	151.6	149.9	152.0
4	M	148.0	149.5	152.6
4	M	151.6	151.1	150.4
4	M	150.4	150.6	152.2
4	M	145.2	146.1	149.7
5	J	140.6	142.6	141.6
5	J	140.6	142.4	139.8

LOT	TYP	CPNBS	TROXLR	SEAMAN
5	J	135.5	141.3	136.3
5	J	137.5	142.9	141.6
5	J	140.1	141.0	138.8
5	J	143.2	143.5	143.3
5	J	142.2	141.3	139.9
5	J	141.1	144.4	140.5
5	J	138.0	138.5	138.4
5	J	136.0	139.7	132.6
5	J	137.5	138.9	136.0
5	J	137.6	139.8	140.1
5	M	142.2	143.1	142.2
5	M	146.0	148.5	146.6
5	M	153.1	156.0	156.7
5	M	143.8	150.2	150.7
5	M	146.0	147.7	147.3
5	M	150.7	152.1	151.5
5	M	153.7	153.7	154.8
5	M	147.1	150.4	148.0
5	M	148.9	146.4	148.5
5	M	150.7	154.1	155.4
5	M	144.9	148.3	149.5
5	M	147.4	148.4	153.8
5	M	149.5	149.9	149.9
6	J	135.7	138.2	132.7
6	J	150.2	151.9	152.8
6	J	136.7	141.3	137.0
6	J	138.2	140.0	141.2
6	J	144.5	147.4	148.0
6	J	138.7	142.4	138.9
6	J	137.7	141.3	143.2
6	J	135.7	141.0	133.7
6	J	140.7	140.1	143.6
6	J	139.2	140.8	143.2
6	J	140.7	145.3	152.6
6	J	142.9	144.8	146.2
6	J	142.9	145.3	145.3
6	J	145.0	145.7	148.8
6	J	149.6	150.0	149.4
6	J	140.2	141.3	145.3
6	M	144.5	143.3	146.7
6	M	152.6	155.8	157.1
6	M	155.1	155.2	157.4
6	M	147.9	153.3	151.4
6	M	1 5.8	158.0	159.0
6	M	152.0	149.2	153.4
6	M	142.7	141.1	148.1
6	M	146.7	149.2	152.8
6	M	146.7	153.1	151.2
6	M	156.4	152.7	157.7
6	M	150.8	153.0	151.4
6	M	150.2	148.5	151.4
6	M	149.6	152.4	157.8

LOT	TYP	CPNBS	TROXLR	SEAMAN
6	M	152.6	151.3	152.0
7	J	134.8	139.3	126.9
7	J	139.2	142.3	137.4
7	J	140.9	147.1	142.0
7	J	145.8	148.5	147.9
7	J	149.2	153.2	152.6
7	J	144.6	145.1	144.4
7	J	141.4	144.0	145.4
7	J	133.5	137.0	136.5
7	J	151.6	151.3	151.7
7	J	146.3	144.2	144.0
7	J	138.8	140.0	141.4
7	J	139.9	141.1	139.3
7	J	138.6	142.2	146.4
7	J	138.6	136.4	138.7
7	J	133.0	138.8	136.0
7	J	137.8	142.8	142.6
7	J	128.7	129.8	128.8
7	J	134.2	136.6	134.5
7	M	149.0	151.9	151.2
7	M	148.6	147.4	150.4
7	M	139.3	140.7	142.1
7	M	148.6	150.9	149.3
7	M	149.2	154.9	152.9
7	M	146.3	149.0	148.0
7	M	148.0	152.4	151.1
7	M	152.2	155.1	154.2
7	M	154.0	157.6	157.1
7	M	152.2	155.1	157.2
7	M	155.9	158.6	156.9
7	M	139.3	144.9	141.1
7	M	145.8	149.3	149.9
7	M	154.7	154.1	151.3
7	M	146.9	148.9	149.8
7	M	150.4	150.1	147.2
7	M	140.2	145.4	137.3
7	M	146.2	149.6	152.0
7	M	151.4	153.8	156.6
7	M	147.3	149.8	143.4
7	M	146.7	149.1	151.0
8	J	134.5	139.6	141.1
8	J	127.7	125.9	128.0
8	J	137.0	142.1	141.0
8	J	128.7	134.6	134.8
8	J	126.8	133.6	137.9
8	J	129.9	132.2	133.7
8	J	129.9	134.8	134.2
8	J	121.1	122.5	122.0
8	J	137.0	139.0	139.5
8	J	130.8	135.7	133.9
8	J	135.5	140.5	138.0
8	J	126.4	130.9	133.8

LOT	TYP	CPNBS	TROXLR	SEAMAN
8	J	133.6	131.4	135.5
8	J	130.8	135.2	133.1
8	J	120.2	124.4	122.0
8	J	143.7	148.0	148.0
8	J	123.8	128.6	132.9
8	J	140.5	143.4	144.1
8	J	130.8	136.6	133.4
8	J	131.3	134.9	136.4
8	J	149.7	151.6	154.3
8	M	148.2	150.7	150.1
8	M	143.7	147.1	149.1
8	M	145.9	146.1	147.5
8	M	148.2	146.4	147.8
8	M	144.8	147.8	151.1
8	M	147.0	149.8	154.0
8	M	142.1	145.1	149.2
8	M	144.3	147.3	150.5
8	M	142.1	147.7	146.4
8	M	151.0	154.1	157.2
8	M	141.0	144.4	144.5
8	M	145.4	149.9	153.4
8	M	143.2	145.5	149.5
8	M	147.0	150.2	153.5
8	M	145.9	147.5	145.2
8	M	146.5	151.8	152.2
8	M	148.8	147.6	149.8
8	M	145.4	148.0	149.3
8	M	150.5	152.1	154.8
8	M	151.7	151.7	155.3
9	J	137.3	141.1	137.1
9	J	138.8	145.5	144.7
9	J	136.8	145.3	142.5
9	J	135.8	141.1	140.2
9	J	134.4	139.2	137.4
9	J	131.1	134.1	132.4
9	J	134.8	140.0	137.3
9	J	143.0	144.6	142.6
9	J	130.2	134.0	129.0
9	J	134.4	141.1	134.1
9	J	139.3	140.5	144.9
9	J	138.8	139.9	135.5
9	J	133.0	135.6	139.6
9	J	137.3	142.8	142.9
9	J	139.3	143.6	141.6
9	J	136.8	142.7	140.7
9	J	137.8	137.5	136.9
9	J	141.9	140.2	139.7
9	M	144.6	146.7	147.9
9	M	145.7	151.1	151.8
9	M	150.3	153.8	152.3
9	M	144.6	141.0	142.9
9	M	139.8	143.7	139.5

AD-A155 773 STUDY OF ACCEPTANCE CRITERIA FOR JOINT DENSITIES IN BITUMINOUS AIRPORT PA..(U) CLEMSON UNIV S C DEPT OF CIVIL ENGINEERING J L BURATI ET AL. FEB 85 2/2

UNCLASSIFIED DOT/FAA/PM-85/5 DTFA01-81-C-10057 F/G 1/5 NL

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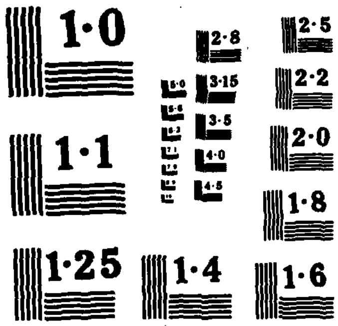

NATIONAL BUREAU OF STANDARDS
MICROCOPY RESOLUTION TEST CHART

LOT	TYP	CPNBS	TROXLR	SEAMAN
9	M	146.2	153.3	151.0
9	M	143.5	149.9	149.2
9	M	152.7	153.9	152.6
9	M	155.8	156.7	155.6
9	M	145.1	150.1	149.6
9	M	150.9	154.9	156.5
9	M	145.7	150.5	149.2
9	M	148.5	149.1	151.7
9	M	144.0	147.5	149.9
9	M	143.0	146.7	148.4
9	M	144.0	148.0	149.8
9	M	143.5	148.4	147.3
9	M	144.0	149.3	149.8
10	J	129.9	135.8	133.1
10	J	133.6	134.4	135.3
10	J	123.4	128.6	127.3
10	J	131.2	135.2	135.0
10	J	130.3	135.6	134.1
10	J	132.2	138.4	136.2
10	J	130.8	135.1	132.8
10	M	155.0	154.3	157.5
10	M	146.0	150.1	151.2
10	M	133.6	139.1	138.0
10	M	139.0	148.3	145.3
10	M	146.6	150.9	150.3
10	M	149.5	151.3	152.8
10	M	146.6	150.6	148.2

The acceptance test location density results for the Rochester project are listed below. The column labeled TYP identifies whether the values are for mat (M) or joint (J) readings. The CPNBS, TROXLR, SEAMAN and CORE columns are for the CPN gage in the BS mode, the Troxler gage, the Seaman gage and the core results, respectively.

Acceptance Test Location Density Results - Rochester

LOT	TYP	CPNBS	TROXLR	SEAMAN	CORE
1	J	136.4	141.7	139.5	137.3
1	J	126.4	127.0	128.9	126.8
1	J	144.1	147.6	147.5	146.7
1	J	145.8	145.4	147.6	141.1
1	M	153.9	153.4	154.0	151.7
1	M	153.9	146.9	152.7	152.1
1	M	150.9	151.0	156.2	153.6
1	M	151.5	143.2	149.8	151.2
2	J	143.0	139.2	146.5	145.2
2	J	139.9	138.5	140.0	141.0
2	J	135.0	140.6	141.6	142.6
2	J	140.9	143.7	146.3	140.6
2	M	148.6	148.2	151.5	150.3
2	M	150.3	153.2	152.1	152.4
2	M	143.0	142.9	146.7	150.0
2	M	149.1	147.2	146.6	147.5
3	J	144.1	150.7	150.1	147.0
3	J	152.4	146.1	147.3	148.5
3	J	149.1	145.0	147.7	149.2
3	J	149.1	154.1	147.7	150.6
3	M	145.8	148.0	149.5	150.1
3	M	147.4	150.4	153.0	153.3
3	M	149.7	146.1	150.4	150.5
3	M	152.1	149.8	151.9	153.3
4	J	138.1	140.3	148.5	143.1
4	J	139.1	144.2	150.0	145.9
4	J	147.2	148.2	148.0	147.8
4	J	150.1	149.1	151.5	151.2
4	M	149.5	150.4	153.0	153.1
4	M	151.3	150.6	154.5	154.0
4	M	149.5	148.2	149.9	150.8
4	M	147.2	140.5	149.3	151.0
5	J	143.5	147.7	145.2	146.9
5	J	144.6	141.0	141.3	144.5
5	J	138.7	140.3	136.4	139.7
5	J	134.7	134.2	134.2	138.8
5	M	139.7	144.0	147.9	148.8
5	M	141.8	145.6	148.0	149.1
5	M	139.2	138.4	145.5	145.6
5	M	141.3	141.4	145.9	149.3
6	J	145.2	144.8	140.2	140.8
6	J	140.4	142.1	143.6	143.0
6	J	144.1	144.8	142.8	142.0
6	J	139.3	141.5	143.8	143.4
6	M	144.1	145.3	145.5	151.3
6	M	146.9	146.0	146.7	147.9
6	M	145.8	144.3	150.4	151.4
6	M	145.2	148.9	151.5	152.4
7	J	139.9	142.2	145.6	145.6
7	J	139.9	145.5	143.0	145.6
7	J	138.4	146.8	144.4	147.3
7	J	140.4	148.0	145.8	145.7

LOT	TYP	CPNBS	TROXLR	SEAMAN	CORE
7	M	145.3	146.8	147.5	149.0
7	M	144.7	146.2	146.0	150.4
7	M	144.2	147.9	147.5	150.7
7	M	149.3	150.7	151.7	153.4
8	J	138.8	140.2	143.4	142.9
8	J	139.7	141.3	143.3	140.4
8	J	136.3	144.2	142.9	143.5
8	J	136.8	134.7	137.6	135.4
8	M	144.6	145.0	152.5	148.9
8	M	145.2	147.2	149.2	150.7
8	M	145.8	148.8	152.5	152.0
8	M	141.9	147.4	150.3	149.0
9	J	140.4	135.4	145.5	142.9
9	J	138.4	138.5	146.4	138.6
9	J	137.3	136.5	145.6	141.9
9	J	141.4	140.1	146.0	141.1
9	M	142.5	150.0	149.3	148.7
9	M	144.7	144.0	145.5	152.9
9	M	140.4	143.0	147.1	147.0
9	M	151.0	151.8	154.0	147.8
10	J	135.0	145.3	153.0	141.0
10	J	137.0	142.0	143.4	139.2
10	J	135.0	141.2	143.1	139.2
10	J	136.0	142.3	144.0	138.6
10	M	141.6	148.0	146.9	148.0
10	M	144.3	146.9	153.9	149.2
10	M	144.9	153.2	152.2	151.8
10	M	141.6	143.3	145.2	151.3
11	J	139.0	143.3	145.5	141.3
11	J	135.0	140.8	146.5	137.4
11	J	138.0	142.4	149.5	137.9
11	J	138.0	140.1	137.1	139.8
11	M	147.1	146.5	151.8	150.6
11	M	143.8	148.2	160.3	150.1
11	M	142.2	143.4	144.3	151.4
11	M	145.4	147.2	148.5	148.7
12	J	133.0	131.3	128.9	137.3
12	J	137.3	141.9	142.0	144.8
12	J	143.0	145.0	144.6	143.8
12	J	141.4	142.0	146.0	146.3
12	M	135.8	145.3	144.0	151.3
12	M	143.6	143.4	149.7	148.4
12	M	145.8	147.0	149.1	151.2
12	M	146.9	147.7	149.2	150.4
13	J	139.3	145.3	147.0	147.3
13	J	139.3	142.9	143.8	146.6
13	J	136.3	141.4	141.4	140.4
13	J	144.1	145.7	152.0	149.8
13	M	148.6	149.5	150.5	149.1
13	M	140.4	147.4	148.5	148.1
13	M	148.6	149.4	151.4	151.7
13	M	142.5	145.1	145.6	149.0

LOT	TYP	CPNBS	TROXLR	SEAMAN	CORE
14	J	136.2	141.9	150.5	138.7
14	J	142.9	145.1	147.1	141.6
14	J	143.4	146.2	146.3	143.6
14	J	143.9	145.5	146.0	145.4
14	M	146.2	151.8	150.3	149.7
14	M	144.5	148.1	148.0	151.2
14	M	145.0	149.0	152.9	149.8
14	M	135.2	140.8	145.1	147.1
15	J	139.7	139.5	142.9	144.8
15	J	139.7	139.3	147.9	141.0
15	J	136.4	133.3	137.4	135.7
15	J	141.8	144.1	151.2	146.3
15	M	145.6	147.7	149.3	147.8
15	M	143.9	146.8	149.9	150.6
15	M	145.6	151.4	152.3	147.5
15	M	145.0	148.2	150.9	148.1
16	J	145.4	145.4	149.1	146.0
16	J	143.8	146.5	142.6	144.4
16	J	147.1	145.3	142.4	141.6
16	J	135.0	142.4	148.1	142.3
16	M	142.8	146.0	145.8	153.4
16	M	146.0	149.4	150.5	152.4
16	M	147.6	149.2	154.6	154.3
16	M	140.1	146.7	148.8	155.0
17	J	145.8	147.0	147.9	149.1
17	J	136.8	143.5	139.9	140.4
17	J	144.7	146.6	148.5	147.3
17	J	145.8	147.7	147.5	146.9
17	M	144.7	149.7	151.8	150.4
17	M	145.8	144.7	150.7	155.1
17	M	144.2	151.6	158.6	152.8
17	M	146.4	144.2	152.7	152.4
18	J	145.8	147.2	148.0	151.0
18	J	144.2	144.6	147.7	147.9
18	J	149.9	148.0	149.2	149.2
18	J	138.2	145.4	145.1	146.8
18	M	149.9	149.8	153.1	150.4
18	M	145.3	147.1	152.4	155.1
18	M	148.7	148.3	153.4	152.8
18	M	152.3	152.1	155.6	152.4

The random location density results for the Rochester project are listed below. The column labeled TYP identifies whether the values are for mat (M) or joint (J) readings. The CPNBS, TROXLR and SEAMAN columns are for the CPN gage in the BS mode, the Troxler gage and the Seaman gage results, respectively.

Random Location Density Results - Rochester

LOT	TYP	CPNBS	TROXLR	SEAMAN
1	J	135.9	146.2	145.2
1	J	138.9	141.5	137.8
1	J	136.4	141.7	142.5
1	J	149.7	155.7	151.6
1	J	146.9	155.7	151.6
1	J	137.4	142.9	141.9
1	J	139.4	147.4	149.9
1	J	134.5	140.4	139.5
1	J	136.4	138.5	137.9
1	J	138.9	140.0	142.1
1	J	136.9	142.1	139.1
1	J	146.3	146.1	143.4
1	J	143.0	142.7	149.0
1	J	135.9	135.3	138.3
1	J	147.4	154.0	136.6
1	M	144.7	147.5	150.9
1	M	149.1	152.2	154.2
1	M	150.9	154.9	151.5
1	M	154.5	153.3	154.6
1	M	149.7	157.1	153.5
1	M	149.7	147.6	148.3
1	M	150.9	144.8	153.9
1	M	143.6	145.6	147.2
1	M	145.8	150.2	152.2
1	M	153.3	148.2	148.9
1	M	149.7	151.6	152.9
1	M	150.9	151.7	147.9
1	M	155.2	149.7	153.4
1	M	143.6	148.2	144.9
1	M	148.6	147.6	153.9
2	J	136.4	143.7	143.4
2	J	139.9	149.0	137.1
2	J	144.1	147.5	140.6
2	J	144.7	147.5	145.0
2	J	137.4	142.3	146.9
2	J	150.9	146.5	139.9
2	J	149.7	153.1	149.1
2	J	138.9	142.1	145.9
2	J	149.1	147.4	146.7
2	J	146.9	143.8	141.8
2	M	146.9	148.9	153.1
2	M	155.8	154.1	156.6
2	M	145.2	148.4	151.9
2	M	153.3	149.7	153.7
2	M	149.7	156.7	149.6
2	M	145.8	151.0	148.7
2	M	156.4	153.5	155.3
2	M	149.1	155.5	149.8
2	M	152.1	159.4	152.6
2	M	155.2	151.3	152.7
3	J	142.8	143.1	146.3
3	J	141.7	141.1	146.3

LOT	TYP	CPNBS	TROXLR	SEAMAN
3	J	138.6	144.5	147.9
3	J	152.5	149.9	149.7
3	J	141.2	147.7	147.1
3	J	146.6	149.4	147.7
3	J	145.5	153.9	147.8
3	J	146.6	149.3	149.0
3	J	145.5	149.4	147.8
3	J	144.4	147.2	145.1
3	J	138.6	142.1	144.8
3	J	136.1	141.9	143.1
3	J	139.7	141.1	146.0
3	J	142.8	146.0	145.0
3	J	140.7	147.3	145.6
3	J	140.2	142.3	144.5
3	J	140.7	143.3	146.2
3	J	142.8	142.6	142.0
3	J	136.6	138.6	144.0
3	J	140.2	143.0	143.6
3	J	147.2	138.9	148.9
3	J	146.1	143.9	143.3
3	J	141.7	144.8	149.2
3	J	142.3	142.9	143.6
3	J	138.6	146.6	147.1
3	J	140.2	143.6	144.4
3	J	141.2	141.3	142.3
3	J	139.7	145.1	144.6
3	J	139.1	135.2	138.0
3	J	147.2	142.6	144.8
3	M	149.5	150.6	149.8
3	M	146.6	146.4	150.7
3	M	145.0	147.7	148.6
3	M	140.7	142.1	146.7
3	M	144.4	150.1	149.8
3	M	146.1	150.7	150.4
3	M	142.8	145.7	147.4
3	M	147.8	148.9	151.7
3	M	146.1	149.5	148.8
3	M	147.2	150.5	151.1
3	M	147.8	148.9	152.1
3	M	145.5	149.7	150.4
3	M	141.1	150.0	150.2
3	M	143.9	151.3	149.1
3	M	142.8	140.2	144.3
3	M	148.9	154.1	152.7
3	M	146.6	150.2	150.0
3	M	144.4	149.4	148.8
3	M	145.0	146.3	146.7
3	M	146.1	149.8	150.5
3	M	146.6	149.3	150.1
3	M	151.3	150.0	150.2
3	M	147.8	151.0	150.6
3	M	148.4	147.1	149.9

LOT	TYP	CPNBS	TROXLR	SEAMAN
3	M	140.7	144.4	148.4
3	M	143.3	147.8	143.6
3	M	147.8	150.5	149.9
3	M	145.5	147.0	151.5
3	M	145.5	143.3	149.3
3	M	147.2	143.4	145.2
4	J	141.3	144.4	145.1
4	J	148.5	144.7	146.3
4	J	145.1	144.8	148.9
4	J	142.9	143.2	148.4
4	J	138.2	141.9	148.0
4	J	142.9	140.1	143.0
4	J	135.2	138.2	141.1
4	J	136.1	140.8	144.8
4	J	143.5	139.4	143.9
4	J	133.3	132.7	144.8
4	J	140.8	142.5	156.7
4	J	147.4	145.3	152.8
4	J	141.3	145.4	150.9
4	J	146.2	150.0	149.3
4	J	145.7	149.0	151.2
4	J	139.7	148.2	151.4
4	J	146.2	144.6	143.9
4	J	145.7	144.0	150.6
4	J	142.9	144.7	148.7
4	J	148.7	143.6	150.5
4	M	142.9	146.9	149.7
4	M	148.0	145.1	149.6
4	M	149.0	147.3	150.8
4	M	149.1	149.0	150.4
4	M	148.6	148.9	151.1
4	M	142.4	142.4	148.8
4	M	144.6	148.4	151.1
4	M	147.4	144.8	149.4
4	M	142.4	146.7	149.0
4	M	154.0	153.1	155.2
4	M	144.0	145.7	149.6
4	M	149.7	145.7	149.6
4	M	146.8	150.3	153.2
4	M	145.1	146.7	148.8
4	M	146.9	149.7	152.2
4	M	141.8	149.3	153.3
4	M	145.1	147.0	151.7
4	M	149.1	149.3	152.4
4	M	149.7	150.7	152.4
4	M	148.0	149.2	152.2
5	J	141.2	145.4	144.4
5	J	145.0	147.8	145.5
5	J	146.6	148.4	148.4
5	J	145.5	148.3	146.5
5	J	141.7	147.5	145.1
5	J	133.3	134.8	134.5

LOT	TYP	CPNBS	TROXLR	SEAMAN
5	J	134.2	137.7	139.2
5	J	139.2	142.7	144.5
5	J	141.8	144.5	138.8
5	J	144.6	145.1	139.9
5	J	137.2	138.8	137.5
5	J	134.2	141.4	148.2
5	J	138.7	141.6	140.7
5	J	135.7	141.4	144.2
5	J	143.5	145.6	137.7
5	M	144.4	145.8	147.6
5	M	142.8	145.2	144.5
5	M	148.9	146.0	149.4
5	M	137.1	139.9	142.7
5	M	143.3	148.2	153.4
5	M	140.3	144.3	144.3
5	M	139.2	143.2	142.9
5	M	142.9	143.7	144.7
5	M	146.8	146.5	152.5
5	M	144.0	143.6	156.9
5	M	138.7	142.5	144.5
5	M	142.9	143.3	149.5
5	M	141.3	142.8	146.8
5	M	139.7	146.3	146.6
5	M	140.3	143.6	143.5
6	J	141.4	144.0	145.3
6	J	143.6	143.6	139.2
6	J	145.8	143.1	142.0
6	J	145.8	142.3	141.9
6	J	142.6	146.9	146.8
6	J	148.6	148.3	145.6
6	J	144.6	140.0	138.9
6	J	142.5	142.0	140.4
6	J	151.0	147.4	140.3
6	J	139.7	148.0	146.1
6	J	141.9	139.6	140.9
6	J	144.6	144.5	142.7
6	J	134.4	140.6	142.0
6	J	143.0	142.7	140.6
6	J	146.3	146.2	142.1
6	J	141.2	142.4	146.4
6	J	138.0	142.0	143.7
6	J	139.1	147.1	144.4
6	J	137.5	141.2	142.7
6	J	142.2	145.9	143.3
6	J	146.1	146.7	141.6
6	J	140.1	141.8	141.8
6	J	145.5	148.5	148.1
6	J	136.5	137.8	141.1
6	J	144.9	141.1	145.5
6	M	140.4	146.4	146.9
6	M	145.8	143.0	147.8
6	M	149.2	146.9	149.7

LOT	TYP	CPNBS	TROXLR	SEAMAN
6	M	148.0	147.5	149.1
6	M	148.6	148.6	150.5
6	M	150.4	147.6	148.4
6	M	149.2	147.3	149.8
6	M	146.3	148.6	150.7
6	M	147.5	147.2	148.7
6	M	146.3	142.7	145.9
6	M	148.6	143.6	149.5
6	M	144.1	147.6	150.9
6	M	148.6	150.2	149.9
6	M	146.3	143.4	146.6
6	M	149.2	147.6	148.7
6	M	143.9	146.8	149.0
6	M	147.8	150.9	150.7
6	M	143.9	147.4	147.1
6	M	148.9	143.0	148.1
6	M	142.8	149.0	150.4
6	M	149.0	149.8	151.2
6	M	147.2	148.0	149.6
6	M	142.8	145.4	146.0
6	M	145.5	145.4	147.4
6	M	142.8	146.0	147.4
7	J	142.0	140.0	142.2
7	J	146.1	142.8	141.6
7	J	142.5	145.3	144.1
7	J	140.9	143.9	145.2
7	J	142.5	142.2	141.7
7	J	147.6	144.5	146.3
7	J	143.5	146.5	144.8
7	J	143.1	143.8	146.8
7	J	144.7	143.4	138.0
7	J	145.3	143.5	146.8
7	J	144.2	141.6	140.3
7	J	141.7	146.5	142.8
7	J	146.4	146.0	144.4
7	J	145.8	140.6	148.1
7	J	143.1	148.1	147.7
7	J	147.6	147.6	146.3
7	J	144.2	138.9	147.4
7	J	146.4	147.7	148.3
7	J	142.5	144.4	142.5
7	J	144.2	146.9	148.1
7	M	144.7	150.1	151.1
7	M	144.7	144.9	150.5
7	M	144.2	149.7	150.7
7	M	143.8	146.1	150.3
7	M	150.5	148.0	152.2
7	M	149.9	147.8	152.0
7	M	150.5	150.4	151.8
7	M	148.1	148.5	150.6
7	M	150.5	149.0	151.2
7	M	147.0	149.1	149.9
7	M	146.4	149.5	150.4
7	M	145.8	148.0	150.4
7	M	148.0	147.9	150.7
7	M	146.4	147.6	147.6
7	M	147.6	146.0	148.7
7	M	148.1	147.4	150.0
7	M	149.9	146.7	152.8
7	M	148.1	149.3	151.7
7	M	146.4	147.6	150.1
7	M	145.3	146.4	149.4

APPENDIX B

PERCENT COMPACTION RESULTS

The percent compaction results for the Morristown project are listed below. The column labeled TYP identifies whether the values are for mat (M) or joint (J) readings. The CPNBS, TROXLR, SEAMAN and CORE columns are for the CPN gage in the BS mode, the Troxler gage, the Seaman gage and the core results, respectively.

LOT	TYP	CPNBS	TROXLR	SEAMAN	CORE
1	J	87.8	89.2	90.2	95.3
1	J	86.8	88.9	86.9	93.6
1	J	90.6	88.2	88.3	94.1
1	J	90.4	91.2	91.4	92.6
1	M	96.2	97.5	96.7	98.7
1	M	95.5	97.0	97.4	98.8
1	M	94.4	95.6	95.1	97.3
1	M	100.0	99.8	100.1	100.3
2	J	88.1	91.2	92.2	94.6
2	J	89.6	90.1	90.3	91.5
2	J	85.1	88.0	86.0	92.8
2	J	86.9	88.6	86.5	90.8
2	M	100.5	98.8	100.1	100.4
2	M	97.7	96.5	99.4	99.3
2	M	99.3	97.5	99.8	97.8
2	M	91.8	93.1	94.3	95.4
3	J	86.4	88.0	87.4	95.4
3	J	77.3	80.3	77.3	90.5
3	J	82.9	85.3	82.2	92.0
3	J	93.2	93.1	84.2	95.4
3	M	93.2	94.4	94.8	96.3
3	M	94.6	94.4	93.6	95.7
3	M	91.5	93.3	92.2	94.3
3	M	96.6	97.7	97.7	98.3
4	J	87.4	85.6	88.2	88.9
4	J	89.1	90.0	92.3	91.9
4	J	83.1	84.6	86.3	90.2
4	J	89.1	88.3	89.4	91.1
4	M	96.3	96.3	97.9	95.0
4	M	90.4	91.6	93.9	94.8
4	M	94.8	93.1	96.1	94.6
4	M	95.9	96.1	96.5	96.7
5	J	87.2	90.7	89.3	91.4
5	J	86.6	90.4	89.4	90.1
5	J	91.9	92.4	95.4	94.6
5	J	89.2	87.9	88.2	91.6
5	M	94.4	96.0	97.1	97.1
5	M	94.8	97.2	95.6	95.7
5	M	93.6	93.4	93.6	95.1
5	M	95.2	95.6	96.6	97.0
6	J	91.2	90.2	93.6	95.4
6	J	85.8	88.9	89.0	92.0
6	J	91.2	91.7	93.1	93.0
6	J	87.5	89.2	92.6	99.5
6	M	93.3	93.8	96.6	95.8
6	M	92.4	93.8	95.7	96.7
6	M	98.7	99.4	100.1	100.3
6	M	94.8	93.8	94.5	95.4
7	J	93.1	94.6	94.8	94.8
7	J	89.3	91.4	91.2	93.6
7	J	90.1	91.6	93.1	95.2
7	J	86.1	86.0	87.9	93.5

LOT	TYP	CPNBS	TROXLR	SEAMAN	CORE
7	M	95.1	96.3	94.3	97.3
7	M	96.2	97.7	99.1	98.6
7	M	88.7	88.7	92.2	94.1
7	M	91.4	91.1	92.9	93.5
8	J	84.7	85.7	81.1	92.3
8	J	89.3	87.5	91.1	93.3
8	J	89.4	91.5	93.1	94.1
8	J	81.2	82.6	83.1	91.0
8	M	95.7	93.8	98.2	99.2
8	M	95.3	95.6	97.8	98.0
8	M	94.1	95.6	97.3	97.3
8	M	93.5	97.7	97.4	98.2
9	J	88.8	89.7	90.2	95.6
9	J	85.7	87.7	86.9	92.3
9	J	84.4	86.7	89.6	93.3
9	J	90.5	94.1	95.0	96.0
9	M	96.7	97.0	97.5	98.7
9	M	98.1	97.1	99.4	99.6
9	M	87.4	91.2	91.9	92.7
9	M	89.8	93.0	92.6	95.7
10	J	89.6	91.0	93.3	95.6
10	J	80.4	83.1	82.7	92.1
10	J	80.6	85.0	83.4	92.4
10	J	84.6	87.5	87.4	92.7
10	M	94.9	93.1	97.3	95.3
10	M	92.9	96.4	94.5	99.6
10	M	91.9	91.5	92.9	98.5
10	M	94.1	97.7	97.5	98.1

The percent compaction results for the Rochester project are listed below. The column labeled TYP identifies whether the values are for mat (M) or joint (J) readings. The CPNBS, TROXLR, SEAMAN and CORE columns are for the CPN gage in the BS mode, the Troxler gage, the Seaman gage and the core results, respectively.

LOT	TYP	CPNBS	TROXLR	SEAMAN	CORE
1	J	88.4	91.9	90.5	89.0
1	J	81.9	82.4	83.6	82.2
1	J	93.4	95.7	95.6	95.1
1	J	94.6	94.3	95.7	91.5
1	M	99.8	99.5	99.8	98.4
1	M	99.8	95.3	99.1	98.6
1	M	97.8	97.9	101.3	99.6
1	M	98.2	92.8	97.1	98.1
2	J	93.0	90.5	95.2	94.4
2	J	91.0	90.0	91.1	91.7
2	J	87.8	91.4	92.1	92.7
2	J	91.6	93.4	95.1	91.4
2	M	96.6	96.4	98.5	97.7
2	M	97.7	99.6	98.9	99.1
2	M	93.0	92.9	95.4	97.5
2	M	96.9	95.7	95.3	95.9
3	J	93.7	98.0	97.5	95.6
3	J	99.1	95.0	95.9	96.6
3	J	96.9	94.3	96.0	97.0
3	J	96.9	100.2	96.0	97.7
3	M	94.8	96.2	97.2	97.5
3	M	95.8	97.8	99.5	99.8
3	M	97.3	95.0	97.8	97.8
3	M	98.9	97.4	98.7	97.8
4	J	89.1	90.5	95.8	92.4
4	J	89.8	93.1	96.9	94.2
4	J	95.0	95.6	95.3	95.4
4	J	96.9	96.2	97.8	97.6
4	M	96.5	97.1	98.7	98.8
4	M	97.6	97.3	99.7	99.4
4	M	96.5	95.6	96.7	97.3
4	M	95.0	90.7	96.4	97.5
5	J	93.2	95.9	94.3	95.4
5	J	93.9	91.6	91.7	93.8
5	J	90.0	91.1	88.6	90.7
5	J	87.5	87.1	87.1	90.1
5	M	90.7	93.5	96.0	96.6
5	M	92.1	94.5	96.1	96.8
5	M	94.4	89.9	84.5	94.5
5	M	91.7	91.8	94.7	94.5
6	J	95.2	94.9	91.9	92.3
6	J	92.1	93.2	94.2	93.8
6	J	94.5	94.9	93.6	93.1
6	J	91.3	92.8	94.3	94.0
6	M	92.4	95.3	95.4	99.2
6	M	96.3	95.7	96.2	97.0
6	M	95.6	94.6	98.6	99.3
6	M	95.2	97.6	99.3	99.9
7	J	90.9	92.5	94.7	97.4
7	J	90.9	94.6	93.0	97.7
7	J	90.0	95.5	93.9	95.8
7	J	91.2	96.2	94.8	97.4

LOT	TYP	CPNBS	TROXLR	SEAMAN	CORE
7	M	94.5	95.4	95.9	96.9
7	M	94.1	95.1	94.9	97.8
7	M	93.7	96.2	95.9	98.0
7	M	97.1	98.0	98.6	99.7
8	J	90.6	91.5	93.6	93.3
8	J	91.2	92.2	93.5	91.7
8	J	89.0	94.1	93.3	93.7
8	J	89.3	87.9	89.8	88.4
8	M	94.4	94.7	99.6	97.2
8	M	94.8	96.1	97.4	98.4
8	M	95.2	97.1	99.6	99.2
8	M	92.6	96.2	98.1	97.3
9	J	90.1	87.7	94.3	92.5
9	J	89.7	89.8	94.9	89.8
9	J	89.0	88.5	94.4	92.0
9	J	91.6	94.5	95.9	93.2
9	M	92.4	97.2	96.7	97.4
9	M	93.8	93.3	94.3	99.1
9	M	90.1	92.7	95.3	95.3
9	M	97.8	98.4	99.8	95.8
10	J	88.9	95.6	100.7	92.8
10	J	90.2	93.5	94.4	91.6
10	J	88.9	92.9	94.2	91.6
10	J	89.5	93.7	94.8	91.3
10	M	93.2	97.4	96.7	97.4
10	M	95.0	96.7	101.3	98.2
10	M	95.4	100.1	100.1	99.9
10	M	93.2	94.3	95.6	100.7
11	J	91.6	94.5	95.9	93.2
11	J	89.0	92.8	96.6	90.1
11	J	91.0	93.9	98.6	90.6
11	J	91.0	92.4	90.4	92.2
11	M	97.0	96.6	100.0	99.3
11	M	94.8	97.7	105.1	98.9
11	M	93.7	94.5	95.1	99.8
11	M	95.9	97.1	97.9	98.0
12	J	86.7	85.6	84.1	89.6
12	J	89.6	92.6	92.6	94.4
12	J	93.3	94.6	94.3	93.8
12	J	92.2	92.6	95.2	95.4
12	M	88.6	94.8	93.9	98.7
12	M	93.7	93.5	97.6	96.8
12	M	95.1	95.9	97.3	98.6
12	M	95.8	96.3	97.3	98.1
13	J	91.1	94.9	96.1	96.3
13	J	91.1	93.4	94.0	95.8
13	J	89.1	92.4	92.4	91.8
13	J	94.2	95.2	99.3	97.9
13	M	97.1	97.7	98.7	97.4
13	M	91.7	96.3	97.1	96.8
13	M	97.1	97.6	98.9	99.1
13	M	93.1	94.8	95.2	97.4

LOT	TYP	CPNBS	TROXLR	SEAMAN	CORE
14	J	89.1	92.9	98.5	90.8
14	J	93.3	95.0	[illegible]5.3	92.7
14	J	93.8	95.7	95.7	94.0
14	J	94.2	95.2	95.6	95.2
14	M	95.6	99.3	98.4	98.0
14	M	94.6	96.9	96.8	98.9
14	M	94.9	97.5	100.0	98.0
14	M	88.5	92.1	94.9	96.3
15	J	91.6	91.5	93.7	95.0
15	J	91.6	91.2	97.0	92.5
15	J	89.5	87.4	90.1	89.0
15	J	93.0	94.5	99.2	95.9
15	M	95.5	96.9	97.9	96.9
15	M	94.4	96.3	98.3	98.8
15	M	95.5	99.3	99.9	97.1
15	M	95.1	97.2	99.0	97.1
16	J	95.0	95.0	97.4	94.5
16	J	93.9	97.5	93.2	94.3
16	J	96.1	94.9	93.0	92.5
16	J	88.3	93.0	96.7	93.0
16	M	93.3	95.4	95.2	100.2
16	M	95.4	97.6	98.3	99.6
16	M	96.4	97.5	101.0	100.8
16	M	91.5	95.8	97.2	101.2
17	J	94.3	95.0	95.6	96.4
17	J	88.4	92.8	90.4	90.8
17	J	93.6	94.8	96.1	95.2
17	J	94.3	95.5	95.4	95.0
17	M	93.6	96.8	98.1	97.2
17	M	94.3	93.6	97.4	100.3
17	M	93.2	98.0	102.5	98.8
17	M	94.7	93.2	98.7	98.5
18	J	94.3	95.2	95.7	97.6
18	J	93.2	93.5	95.5	95.6
18	J	96.9	95.7	96.5	96.5
18	J	89.4	94.0	93.8	94.9
18	M	96.9	96.8	99.0	97.3
18	M	93.9	95.1	98.5	100.3
18	M	96.1	95.9	99.2	98.8
18	M	98.5	98.3	100.3	98.6

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